US Army Corps
of Engineers
Water Resources
Support Center

Management of Bottom Sediments Containing Toxic Substances

Proceedings of the 9th US/Japan
Experts Meeting

17-19 October 1983
Jacksonville, Florida

Thomas R. Patin, Editor

March 1985

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The 9th U. S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held 17-19 October 1983 in Jacksonville, Florida. The meeting is held annually through an agreement with the U. S. Army Corps of Engineers and the Japan Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment. Keywords;

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PREFACE

The 9th U. S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held 17-19 October 1983 in Jacksonville, Fla., USA. The meeting is held annually through an agreement with the U. S. Army Corps of Engineers and the Japan Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment.

COL George R. Kleb, Commander and Director of the Water Resources Support Center (WRSC), was the U. S. Chairman. Mr. Ikuhiko Yamashita, Ministry of Transport, Tokyo, Japan, was the Japanese Chairman.

Coordinator of the organizational activities and editor of this report was Mr. Thomas R. Patin, program assistant, Dredging Operations Technical Support Program (DOTS), U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. Mr. Charles C. Calhoun, Jr., was Program Manager, DOTS. At the time of publication of this report, Dr. Robert E. Engler was Program Manager of DOTS.

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ATTENDEES

9th ANNUAL
U.S./JAPAN EXPERTS MEETING

Japanese Delegation

Mr. Ikuhiko Yamashita, Cochairman	Director, Environmental Protection Division, Bureau of Ports and Harbours, Ministry of Transport
Mr. Shoichi Hamaguchi	Deputy Head, Construction Section, Mie Prefectural Government
Mr. Mitsumasa Okada	Researcher, Laboratory of Freshwater Environment, National Institute for Environmental Studies, Environment Agency
Mr. Motoo Fujiki	Professor, Environmental Medicine, Institute of Community Medicine, University of Tsukuba
Mr. Takao Yoshida	Japan Bottom Sediments Management Association
Mr. Yooji Kurimoto	Japan Bottom Sediments Management Association
Mr. Tatsuo Kotake	Japan Bottom Sediments Management Association
Mr. Makoto Natori	Japan Bottom Sediments Management Association
Mr. Hiromi Koba	Japan Dredging and Reclamation Engineering Association
Mr. Ichiro Ofuji	Japan Workvessel Association
Mr. Naoshi Ishimatsu	Japan Workvessel Association
Mr. Iwao Danjo	Japan Bottom Sediments Management Association
Mr. Takatoshi Inoue	Takenaka Komuten Construction Company
Mr. M. Nakamura	Japan Bottom Sediments Management Association

U.S. Delegation

Colonel George R. Kleb, Cochairman	Commander/Director, Water Resources Support Center, Corps of Engineers
Mr. William R. Murden	Chief, Dredging Division, Water Resources Support Center, Corps of Engineers
Mr. Robert Engler	Corps of Engineers, Waterways Experiment Station
Mr. Paul R. Erickson	Director, EnvironEnergy Technology Center, Corporate Research and Innovation Group, Rexnord Corporation
Mr. Michael J. Cruickshank	Minerals Management Service, Department of the Interior
Mr. David Robb	St. Lawrence Seaway Development Corporation, Department of Transportation
Ms. Carol A. Coch	Corps of Engineers, New York District
Mr. Jeff McKee	Corps of Engineers, Baltimore District
Mr. R. F. Brissette	Canonie Engineers, Canonie Environmental Services Corporation
Mr. John D. Luns	Corps of Engineers, Waterways Experiment Station
Mr. Charles C. Calhoun	Corps of Engineers, Waterways Experiment Station
Mr. James Bradley	Corps of Engineers, South Atlantic Division
Mr. Girlamo Di Chiara	Corps of Engineers, Jacksonville District
Mr. Neill E. Parker	Institute for Water Resources, Water Resources Support Center, Corps of Engineers

AGENDA

9th U.S./JAPAN EXPERTS MEETING ON MANAGEMENT
OF BOTTOM SEDIMENTS CONTAINING
TOXIC SUBSTANCES

Jacksonville, Florida

17-19 October 1983

Cochairmen

Mr. Ikuhiko Yamashita

Director, Environmental Protection Division
Ports and Harbours Bureau, Ministry of Transport

COL George R. Kleb

Commander/Director, Water Resources Support Center, U. S. Army
Corps of Engineers

Monday, October 17, 1983

0830	Welcoming Remarks Response Response	Brigadier General Gay - Chairman Yamashita - Chairman Kleb
0900	Aeration Effects on Marine Eutrophication	- Mr. Yamashita
0930	Hypolimnetic Oxygen Deficit in a Eutrophic Lake and the Role of Sediment Oxygen Demand	- Mr. Okada
1000	Break	
1030	Theoretical Considerations of Gravity Dewatering of Dredged Material Through the Bottom of a Containment Area	- Mr. Yoshida
1100	Rapid Dewatering Test of Dredged Material In Situ	- Mr. Nakamura
1130	Lunch	
1300	Mechanical Dewatering	- Mr. Erickson

1330	Dispersion of Sediment Resuspension Caused by Dredge Operation	- Mr. Koba
1400	An Anti-Turbidity Overflow System Used for Reducing the Dispersion of Fine Sediments from a Dredge Plume	- Mr. Cruickshank
1430	Break	
1500	New Techniques Developed in Japan for Oil Spill Cleanup	- Mr. Ofuji
1530	Theoretical Consideration of Pond and Spillwater Treatment Design	- Mr. Natori
1600	St. Lawrence Seaway Precise Navigation	- Mr. Robb
1630	Adjourn	

<u>Tuesday, October 18, 1983</u>

0800	Measurement of Nutrient Concentrations in Sediment Pore Water Collected by a Dialysis Sampler	- Mr. Kurimoto
0830	Accumulation of Acrylamide into Fish	- Mr. Fujiki
0900	London Dumping Convention Update	- Mr. Engler
0930	Alternatives to Open Water Disposal of Contaminated Dredged Material	- Ms. Coch
1000	Break	
1030	Disposal Area Management	- Mr. McKee*
1100	Rehabilitation of Estuaries In Tsu-Matsusaka Harbor	- Mr. Hamaguchi
1130	Lunch	
1300	Subsurface Investigation for Dredging Projects	- Mr. Brissette
1330	Beneficial Uses of Dredged Material	- Mr. Lunz
1400	Break	
1430	Closing Remarks	- Chairman Kleb - Chairman Yamashita
1530	Adjourn	

* No text available.

JOINT COMMUNIQUE

The ninth meeting of experts pursuant to the Agreement Between the Government of Japan and the Government of the United States of America on Cooperation in the Field of Environmental Protection was co-chaired by Mr. Ikuhiko Yamashita, Director, Environmental Protection Division, Ports and Harbours Bureau, Ministry of Transport, Japan, and Colonel George R. Kleb, Commander and Director, Water Resources Support Center, U. S. Army Corps of Engineers. The purpose of the meetings conducted under this agreement is the exchange of information in regulatory, technical, and operational areas relevant to management of bottom sediments and the exploration of areas where joint effort appears fruitful.

Experts from both countries presented technical papers on a variety of subjects including arresting and reversing eutrophication in both saltwater and freshwater water bodies, dewatering of dredged sediments, control and minimization of turbidity during dredging, management of dredged sediment disposal and containment activities, alternatives to ocean disposal of dredged sediments, effects of contaminated sediments on the chemical and biological environments, rehabilitation of contaminated water bodies, and constructive uses for dredged sediments.

This ninth meeting was highly successful and fruitful. The information exchange was very effective. The conferees generally agreed that the dredging technology and sediment management programs of both countries will significantly benefit. The Co-Chairmen agreed that the next meeting will be in Japan in 1984 and that the date will be decided jointly.

Director, Environmental Protection Division, Ports and Harbours Bureau, Ministry of Transport	Commander/Director, Water Resources Support Center, Corps of Engineers
I. Yamashita	George R Kleb
IKUHIKO YAMASHITA Oct. 18, 1983	COLONEL GEORGE R. KLEB Oct. 18, 1983

AERATION EFFECTS ON MARINE EUTROPHICATION

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ABSTRACT

This report briefly presents the results of a study on the application of an aeration system to a marine environment. A multi-hole, tube type aeration device was tested in a nearly closed sea area. The effectiveness of the system, primarily in destratification, was confirmed. This study, which includes preliminary studies on actual examples, laboratory and field experiments, development of simulation systems, etc., is being conducted primarily by the Fifth District Port Construction Bureau of the Ministry of Transport.

BACKGROUND AND OBJECTIVE

Aeration Effect

Organic matter in the water is absorbed, oxidized, and decomposed by aerobic bacteria. Through these processes stable inorganic matter, such as H_2O, CO_2, and nutrient salts, is released into the water when enough dissolved oxygen (DO) is present. In an anaerobic condition, on the other hand, the organics are reduced by anaerobic bacteria evolving methane gas, hydrogen sulfide gas, etc., which may cause an offensive odor. Some nutrient salts would also be released from bottom sediment.

The laboratory experiment showed that the release rate of phosphate-P from the bottom sediment decreases markedly when DO exceeds 2 ppm, as shown in Figure 1.

This fact suggests that depletion of DO in the water can be one of the main causes of deterioration in the quality of water and bottom sediment.

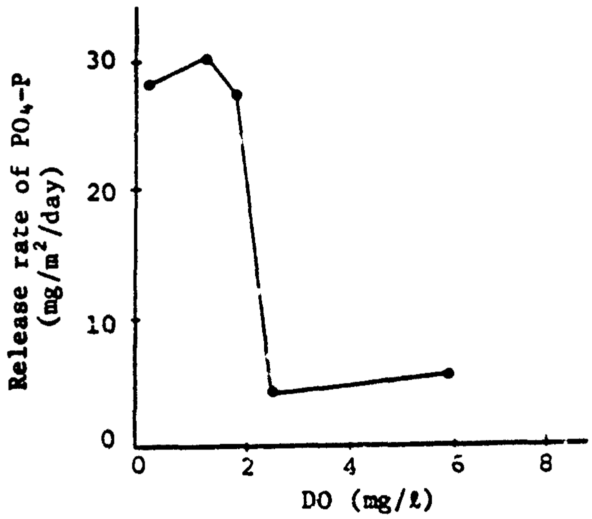

Figure 1. Relationship between release rate of nutrient salts and DO

Also, the aeration which supplies oxygen directly into the water is thought to reduce phosphorus release into eutrophic water. Aeration effects are diagramed in Figure 2. It should be noted from this figure that biochemical and physical factors must be considered. Experiments on aeration systems for lakes and reservoirs have been conducted in several countries and the effectiveness of aeration systems is being clarified. Some systems are being installed for practical use. However, no known aeration systems have yet been applied in seawater. The application of an aeration system in seawater is considered impractical due to the openness of the area. However, it does appear possible to apply an aeration system effectively in a closed or semiclosed bay or port area. Since 1980 the Fifth District Port Construction Bureau has conducted experiments in situ and in the laboratory to investigate the physical and economic viability of an aeration system.

Scope of the Study

This study is being carried out according to the flowchart shown in Figure 3. In the first year (1980), a literature survey was conducted to determine the state of the art in this field and to examine the applicability of aeration systems to ports and bays.

In 1981, a series of laboratory experiments were conducted in cooperation with the Port and Harbour Research Institute to determine DO concentration and flow pattern and destratification caused by aeration.

In 1982, a series of in situ experiments was conducted at the Port of Shimizu in Shizuoka Prefecture to confirm the effects of the multi-hole, tube type aeration system.

Future studies will include the development of a computer simulation program and a series of large-scale field experiments.

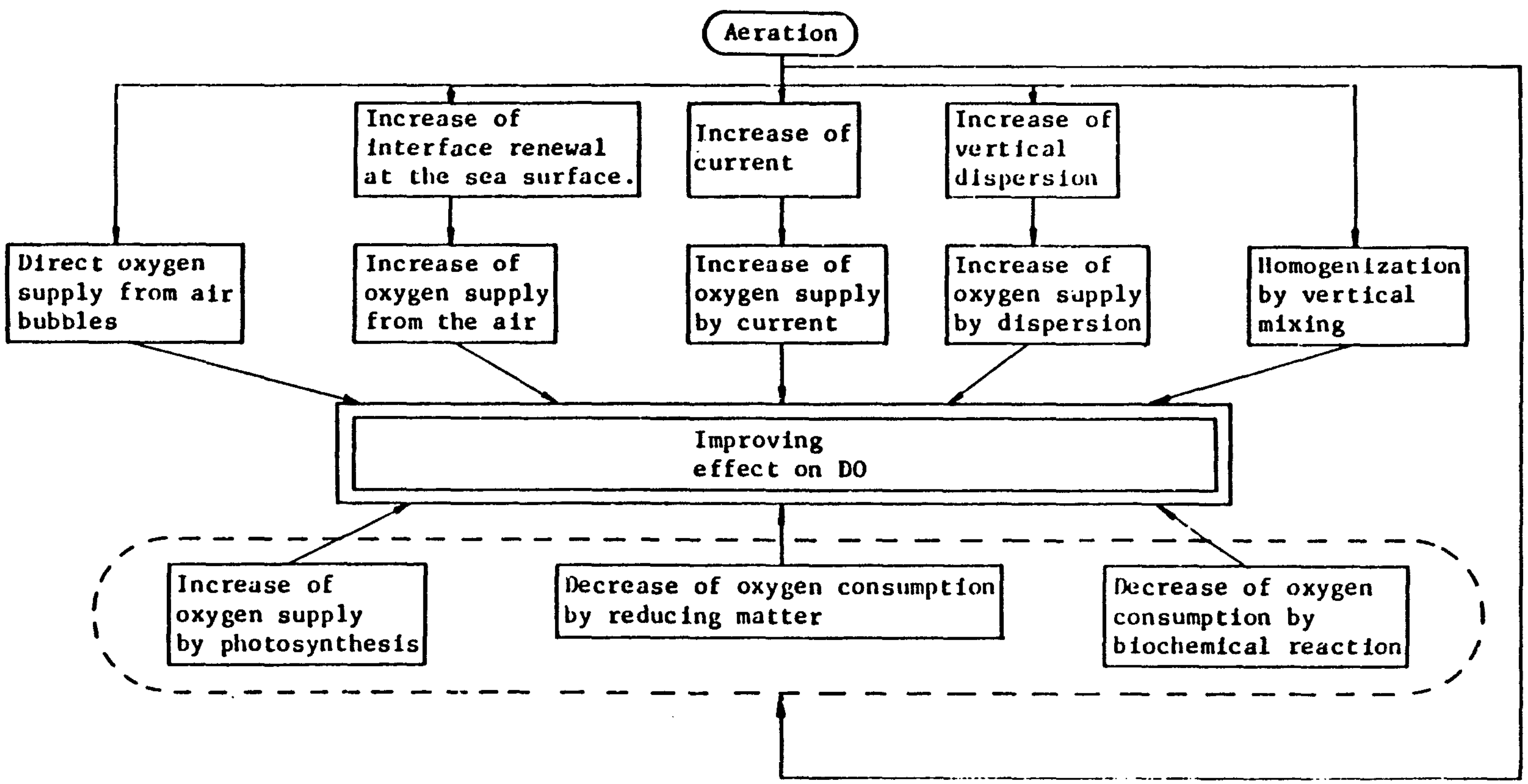

Figure 2. Aeration effects that improve DO

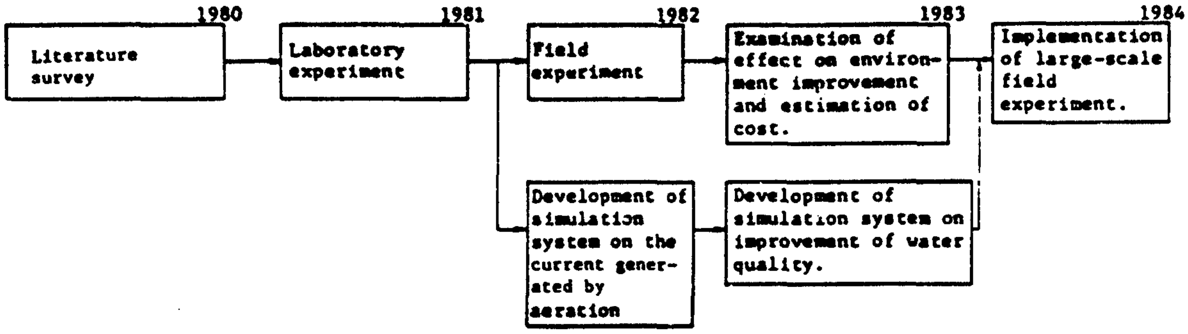

Figure 3. Flowchart of the study

Comparison of Various Aeration Systems (Outline of the 1980 Study)

Most of the aeration systems proposed to date can be classified into three major types: air (oxygen) blowing, mechanical, and hydraulic. These types can be classified further into several minor types as shown in Table 1. The "Number of Examples" column for each type includes those proposed in overseas countries as well as domestic.

The total number of examples is 81, and about half are domestic. Of these, 15 (19% of the total) are at the stage of practical use. Among the total number, the multi-hole, tube type system is dominant.

For DO, oxygen dissolving efficiency,* and power efficiency,† the multi-hole tube system with fine air bubbles has a comparative advantage. This advantage is increased when the vertical mixing of water due to the upward flow of air is considered.

An overall comparison of costs and methods of installation, maintenance and repair, possible secondary pollution, harmony with the surrounding scenery, and influence on marine traffic shows that the multi-hole tube and the wave breaking and/or absorbing systems show high performance.

The hydraulic turbine system is also effective in cases where power-generating turbines are installed at canal zones. Artificial cascades and dams are also considered effective when installed at canal zones. Therefore, these two types have potential application to port and harbour areas.

The system utilizing wave absorbing and breaking actions may satisfy all requirements, but this type is not constructed primarily for aeration; its aeration effect is supplementary. Also, port waters are relatively calm, resulting in less aeration. The surface stirring system seems to be very effective in improving the quality of water from coastal waste disposal sites.

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* Oxygen Dissolving Efficiency $= \dfrac{\text{DO Increase}}{\text{Oxygen Supplied for Aeration}}$

† Power Efficiency $= \dfrac{\text{DO Increase}}{\text{Electric Power Supplied}}$

TABLE 1. AERATION SYSTEMS

Rationale	Aeration Type	Number of Examples	Outline	Examples in Practical Uses
Air blowing	Multi-hole tube (air bubble curtain type)	33	Multi-hole tubes through which air is blown are installed in the water and compressed air is supplied by a compressor.	Protection against inflow of floating refuse and oil, experimental air barrier, etc., at Shinkawa fishing port (Niigata prefecture), Suma seashore (Hyogo prefecture), etc. (six examples).
	Air lift	6	An air chamber is equipped at the bottom of a cylinder and air is sent to the air chamber from a compressor through a hose.	
	Oxygen dissolving	10	Oxygen is used instead of air for aeration. Oxygen is dissolved directly into a polluted water area or into water which is pumped up from a polluted water area. This water is returned to the original water area.	Attica Reservoir and Ottoville Quarry in USA to reduce eutrophication (two examples)
	Air blowing other than above	18	A deepwater aeration method uses the principle of air lift, or a combination of air blowing tubes and a diffuser to make air bubbles.	Waccabuc Lake (USA), Cox Hollow Lake (USA), etc. (three examples).
Mechanical	Surface stirring	4	Water surface is agitated by a turbine stirrer so that air dissolves into the water through the agitated water surface.	This method was applied at Hokko and Nanko of Osaka City for treatment

(Continued)

TABLE 1 (CONTINUED)

Rationale	Aeration Type	Number of Examples	Outline	Examples in Practical Uses
Mechanical (Continued)				of wastewater from the reclaired land (two examples).
	Hydraulic turbine	1	Air or oxygen is introduced into a turbine which is driven by the outflow from a river or a lake.	
Hydraulic	Wave absorption and breaking	1	Method utilizes the phenomenon of dissolution of air into seawater in the form of air bubbles through the disturbed sea surface created by the wave breaking action of shore protection structures.	
	Artificial cascade and dam	2	Method takes air into water while the water flows down an artificial cascade or dam.	
	Water spring	3	Water is exposed to the air increasing the chance to absorb oxygen.	This method was applied at Lotonbori River (Osaka prefecture) and Shakujii Park Pond (Toyko) for improvement of water quality and protection from eutrophication (two examples).

(Continued)

TABLE 1 (CONCLUDED)

Rationale	Aeration Type	Number of Examples	Outline	Examples in Practical Uses
Application of water treatment technique	Conglomerate bed aeration	2	Polluted water absorbs oxygen in an aeration tank, then passes through a conglomerate layer where it is purified by the activity of microorganisms attached on the cobble surface. This method is an application of the trickling filtration process used in a water treatment plant.	
Others	Sea bottom aeration	1	When DO of a sea area is rich, the bottom sediment is stirred and forced to flow up to contact with the upper layer of water which is rich in DO and to be oxidized. At the same time, the void water in the bottom sediment is mixed into seawater and is diluted/diffused.	

From this discussion, it can be seen that every aeration system seems to have potential application to ports and harbours, depending on the installation conditions.

Effect of Aeration in the Laboratory Experiments (Outline of the 1981 Study)

The results of the 1980 study exhibited the applicability of the multi-hole tube system to ports and bays when compared with other systems. Therefore, the laboratory experiment in 1981 concentrated on the multi-hole, tube type aeration. Aeration effect, which depends on shape of air blowing tubes, sizes of air blowing holes, and amount of air blown, was measured and examined using the amount of dissolved oxygen and destratification as indicators.

Experimental Method

A water basin 10 m × 10 m × 1 m was used along with the three types of air blowing tubes shown in Figure 4. Twelve variations were tested with different hole sizes, hole numbers, and varying amount of air. The procedure of the experiments was as follows:

a. In order to reduce the DO, sodium sulfate and cobalt chloride were added to the basin and the water stirred for about 30 min.

b. After the water became still, the initial DO concentration was measured.

c. After aeration began, DO and water flow velocity were measured every 30 min to 1 hr until the DO level reached 7 to 9 ppm.

Results

Results of the experiments are shown in terms of the change of DO in Figures 5-7 and are discussed below:

a. Shape of air blowing tube. As shown in Figure 5, oxygen dissolves the most in B type tubes, and the least for C type tubes. But, the differences among types are not significant. The difference in the oxygen dissolving efficiency among types cannot clearly be seen in the laboratory experiment in which a basin surrounded by walls is used. These walls make outward oxygen dispersion impossible.

b. Size of air blowing holes. As shown in Figure 6, even if the same amount of air, 80 ℓ/min, is blown through the same type tube (C), the amount of dissolved oxygen differs depending on the size of the air holes. It is clear that the smaller the diameter of the hole, the more oxygen that dissolves into the water.

c. Amount of air blown. As shown in Figure 7, three different air levels (80, 150, and 240 ℓ/min) are used and it can be clearly seen that the higher the level, the more the oxygen dissolves.

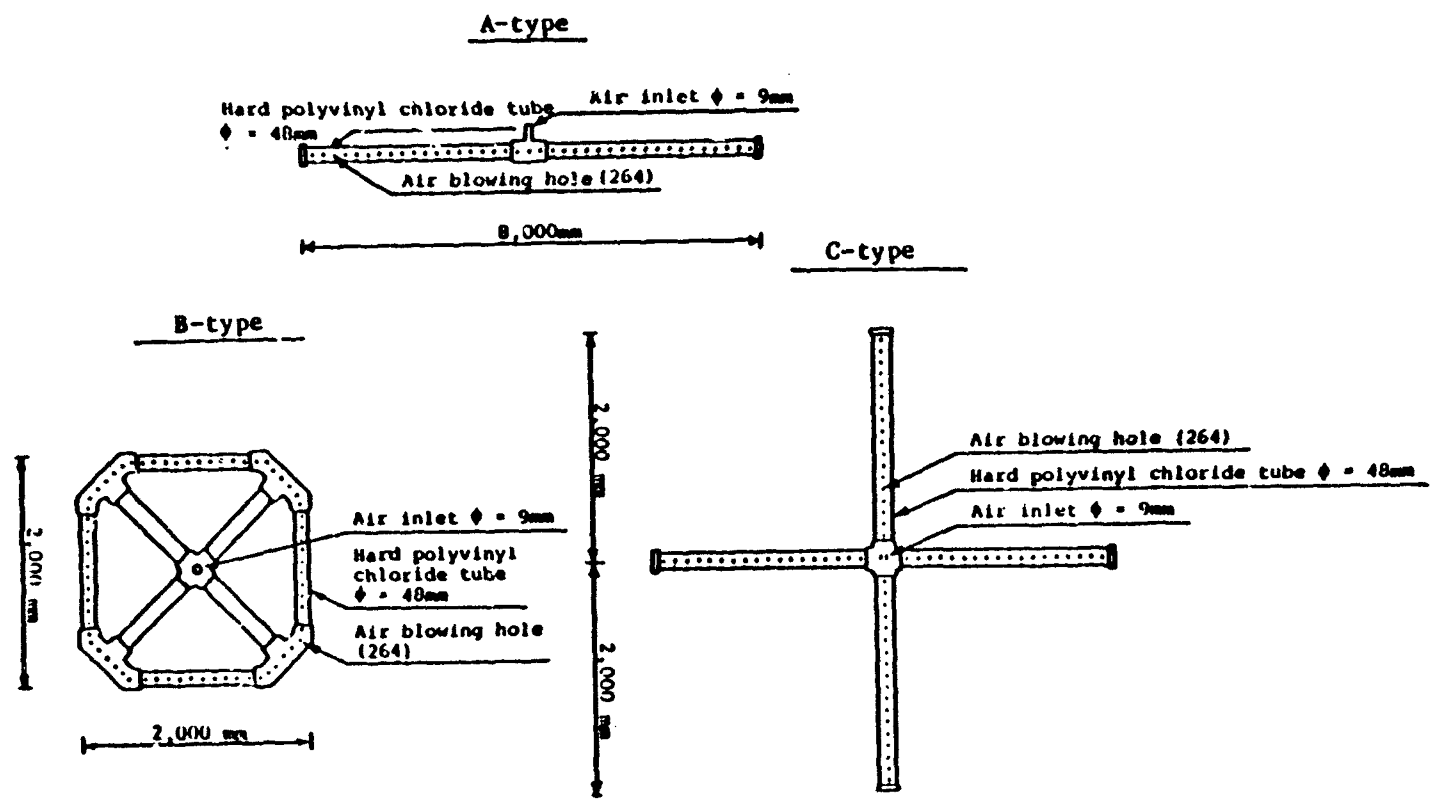

Figure 4. Shapes of air blowing tubes

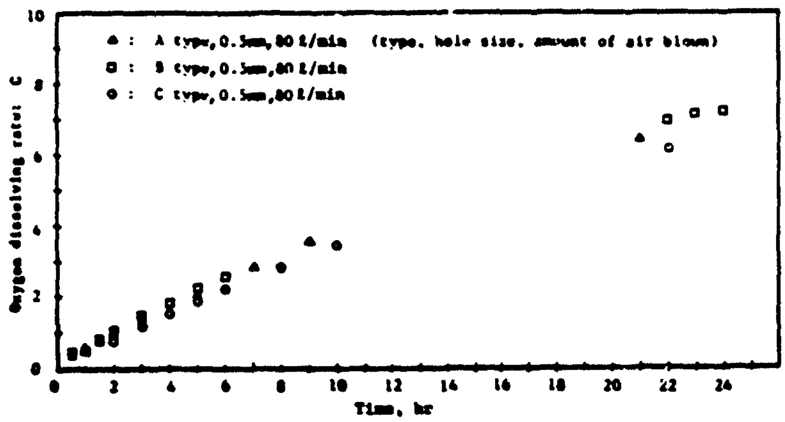

Figure 5. Change of nondimensional oxygen dissolving rate with time, shape of tube

Note: "Non-dimensional oxygen dissolving rate" is expressed as

$$C = \frac{C^* - Co}{Cs - Co}$$

where C^* = Measured concentration of DO (Average value in the testing vessel).
Co = Initial concentration of DO (Average value in the testing vessel).
Cs = Saturated concentration of DO.

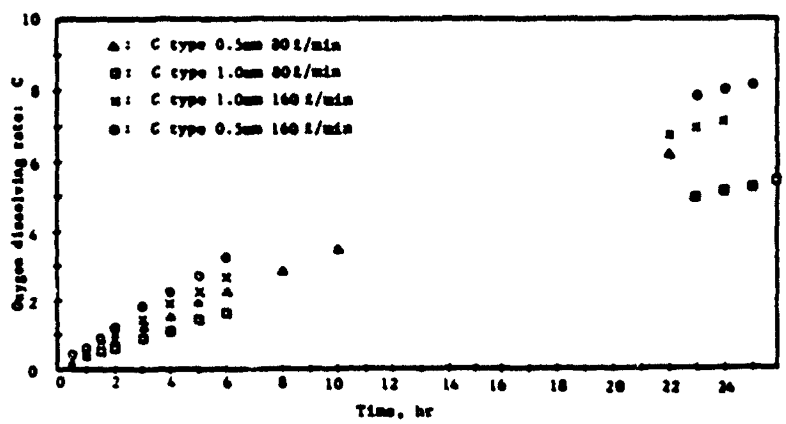

Figure 6. Change of nondimensional oxygen dissolving rate with time, size of hole

Effect of Aeration in the Field Experiment (Outline of the 1982 Study)

The field experiment to determine improvements in water quality caused by aeration was conducted in 1982 at a closed sea area. At this area the exchange of seawater is comparatively small and the seawater has been polluted to a certain degree. Selection of types of air tubes and level of blown air was based on the results of the 1981 laboratory experiment. Flow of seawater, destratification, and change in water quality were measured. The outline of the experiment is discussed in the following paragraphs.

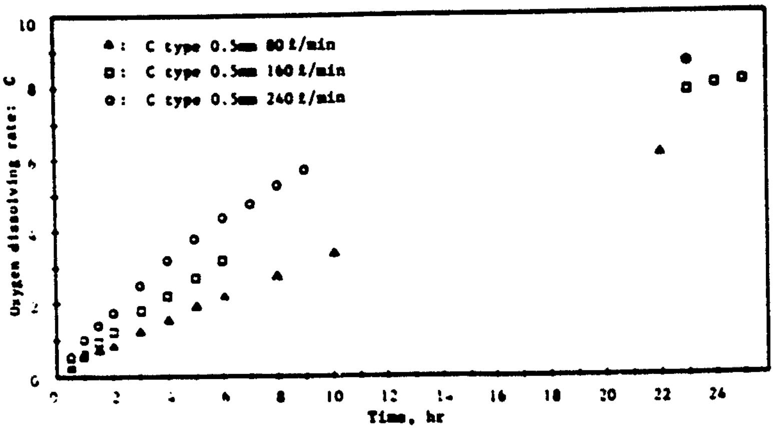

Figure 7. Change of nondimensional oxygen dissolving rate with time, amount of air

Site

As can be seen in Figure 8, a 30- × 70-m area in the No. 1 timber basin at the inner part of Shimizu Port, Shizuoka prefecture, was chosen as the experiment site. The depth of the seawater was 0.5 to 5 m with an average of 3 m. The 39-day experiment was conducted from 2 Aug to 9 Sep 1982.

Methods

The experimental equipment consisted of the air blowing tubes and a compressor.

Two pieces of steel air blowing tubes (4.4 m long, 40 mm in diameter, with 49 holes 1 mm in diameter at intervals of 8.8 m) were connected to an air compression cylinder with a length of 10 m and an inner diameter of 150 mm. Four of these compressed air cylinders were used.

Each tube was installed on the flat seabed as shown in Figure 9. Four tubes were arranged as shown respectively in Figures 10 and 11. One or two compressors with a capacity of 5, 10, and 20 m^3/min were used, depending on cases of the experiment.

Experimental Design

The experiment was carried out for eight cases, each changing the alignment of the aeration tubes, the rate of air blown, and the blowing duration (Table 2).

Observations

The current was observed to determine its generation by aeration. Water temperature and the amount of chlorine were observed to determine the state of stratification. The amount of DO was determined because an increase in DO shows a direct effect of aeration. Turbidity was observed because it indicates possible secondary pollution caused by bottom sediment stirred up by

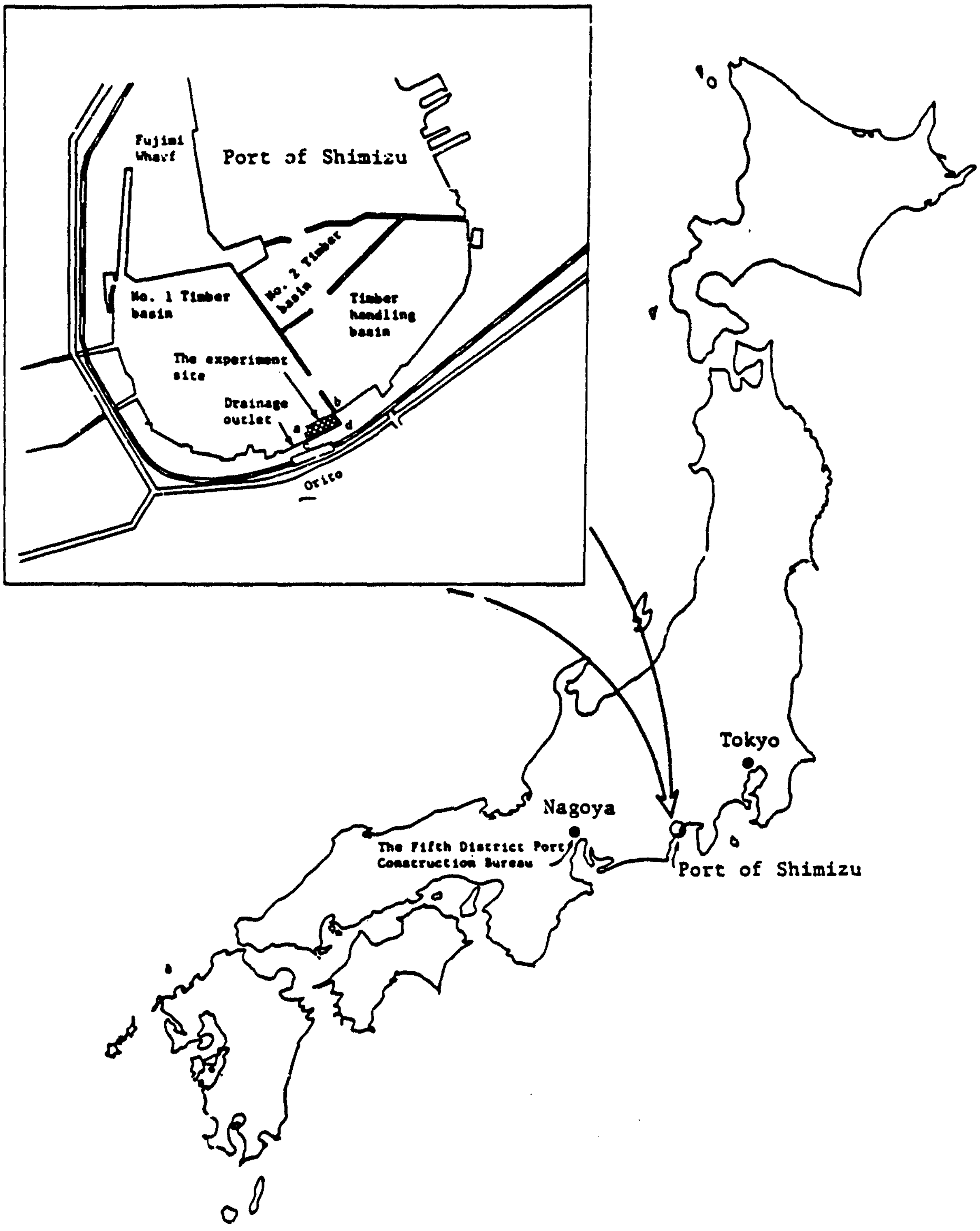

Figure 8. The field experiment site

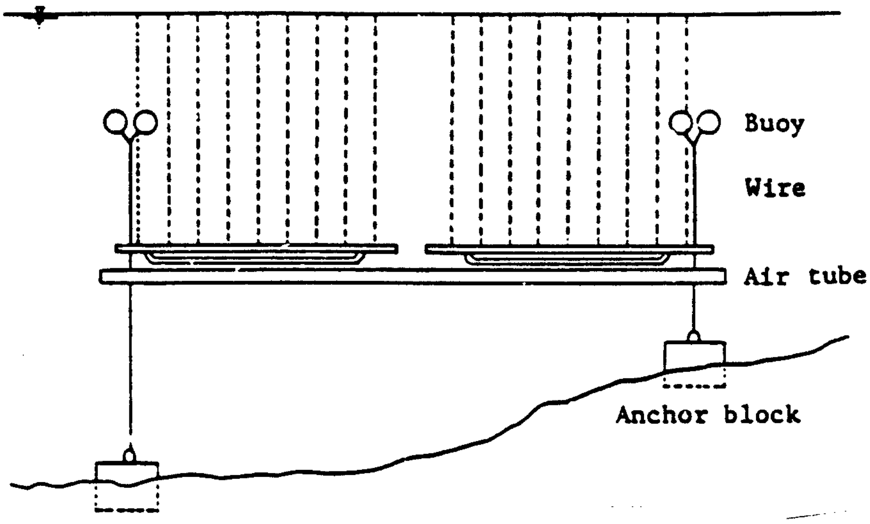

Figure 9. Schematic diagram of air tube installation

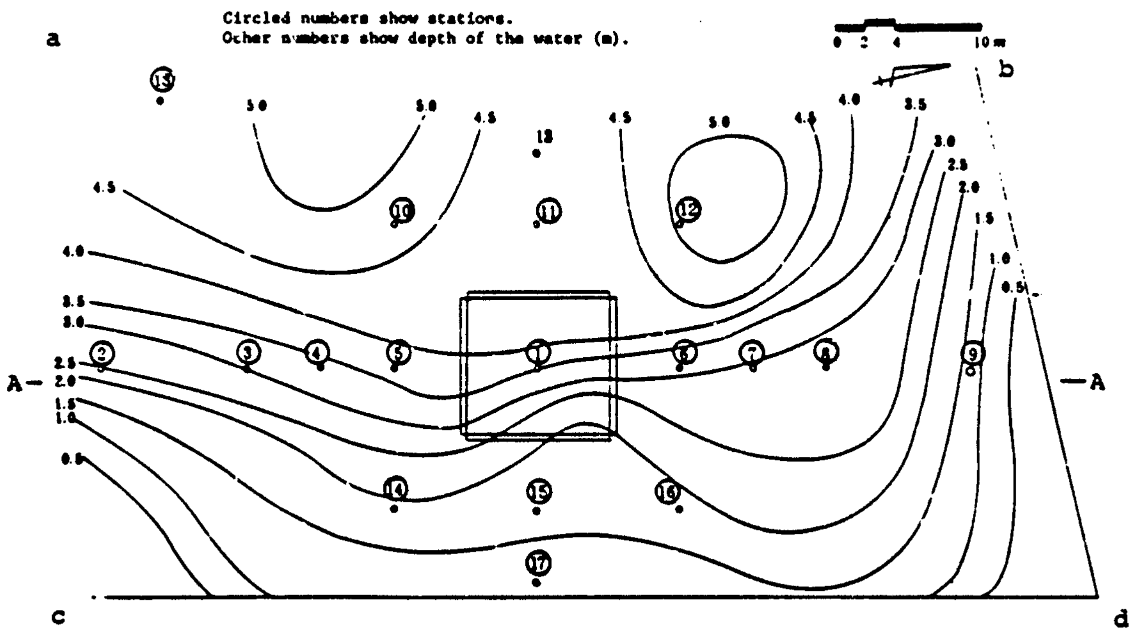

Figure 10. Alignment of the air tubes and stations.
Type I

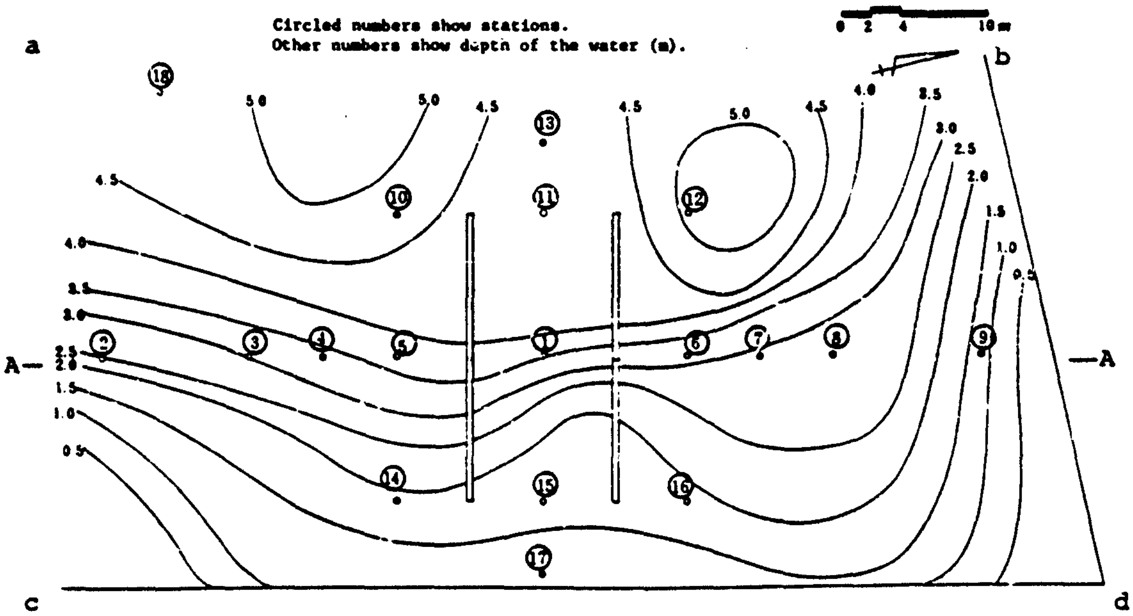

Figure 11. Alignment of the air tubes and stations, Type II

TABLE 2. EXPERIMENTAL CASES

Case	Type*	Rate of Air Blown (Nm^3/min)	Blowing Duration hr	Date of Experiment
1	I	10	24	2-3 Sept 1982
2	I	20	24	6-7 Sept 1982
3	II	10	24	10-11 Aug 1982
4	II	20	24	13-14 Aug 1982
5	II	40	12	16 Aug 1982
6	II	10	144	20-26 Aug 1982
7	II	5	24	18-19 Aug 1982
8	II	10	24	28-29 Aug 1982

* As shown in Figures 10 and 11.

aeration. Chemical oxygen demand and nutrient salts (T-N, T-P, NH_4-N, PO_4-P) were observed to determine decomposition of organic matter and decrease of nutrient salts affected by an increase in DO.

Methods of Measurement

At stations 1 - 18 shown in Figures 10 and 11, horizontal and vertical current directions and current velocities of seawater were measured at depth intervals of 1.0 m from the sea surface to the sea bottom. The measurement was made about every 6 hr corresponding to the low and high tide during the aeration experiment.

To determine change in water quality caused by aeration, water temperature, amount of chlorine, amount of dissolved oxygen, and turbidity were measured with a multipurpose water quality measuring meter and a turbidimeter at the same points and the same times as the current measurements. The measurements were continued for 24 hr with 6-hr intervals after aeration ceased. Changes in organic matter and nutrient salts in the seawater by aeration were measured through samples taken at three points for two layers; COD, T-N, T-P, NH_4-N, and PO_4-P were also measured.

Results

Vertical seawater currents generated by aeration were observed only very close to the air tubes. Horizontal currents, however, prevailed in the surrounding area. The horizontal currents were fairly strong (about 10 cm/sec) more than 30 m away from the air tubes. The results from case No. 3 of the experiment, which is considered a fundamental case, are shown in Figure 12 (current velocity before the experiment was zero).

Changes in the generated water current caused by the differing alignment of the air tubes and the amount of air blown showed that the more the air was blown, the stronger the water current. This effect extended along the direction vertical to the air tubes for the type II arrangement. On the other hand, for the type I, the generated water current was weak and small in scale and the change in the current caused by the rate of blowing air was unclear.

It was clear from the data on the vertical distribution of water temperature, amount of chlorine, etc., that stratification of seawater disappeared 6 hr after aeration began and the seawater within the experimental area was almost homogeneous after 24 hr (Figures 13-16). Six hours after aeration stopped, however, stratification reappeared except for case No. 6. Therefore, the effect of aeration seems to disappear in a fairly short time after aeration ceases. For case No. 6, in which aeration was continued for a long time, the seawater within the experiment area remained comparatively homogenous even 2 days after aeration ceased.

Dissolved oxygen increased rapidly after aeration began and decreased rapidly after aeration ceased. The increase in DO was almost proportional to the amount of air blown. A large fluctuation in the DO level was found during the aeration (Figure 17).

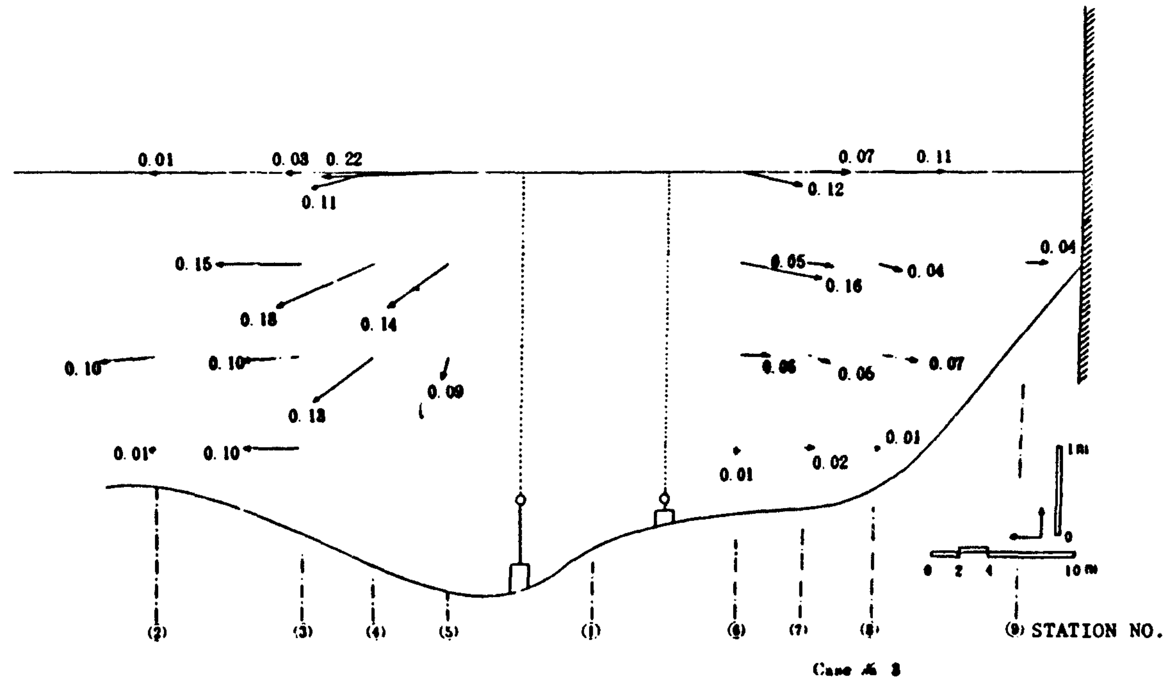

Figure 12. Sectional distribution of flow rate vector -A-A section 24 hr after the beginning of aeration (units are in metres per second)

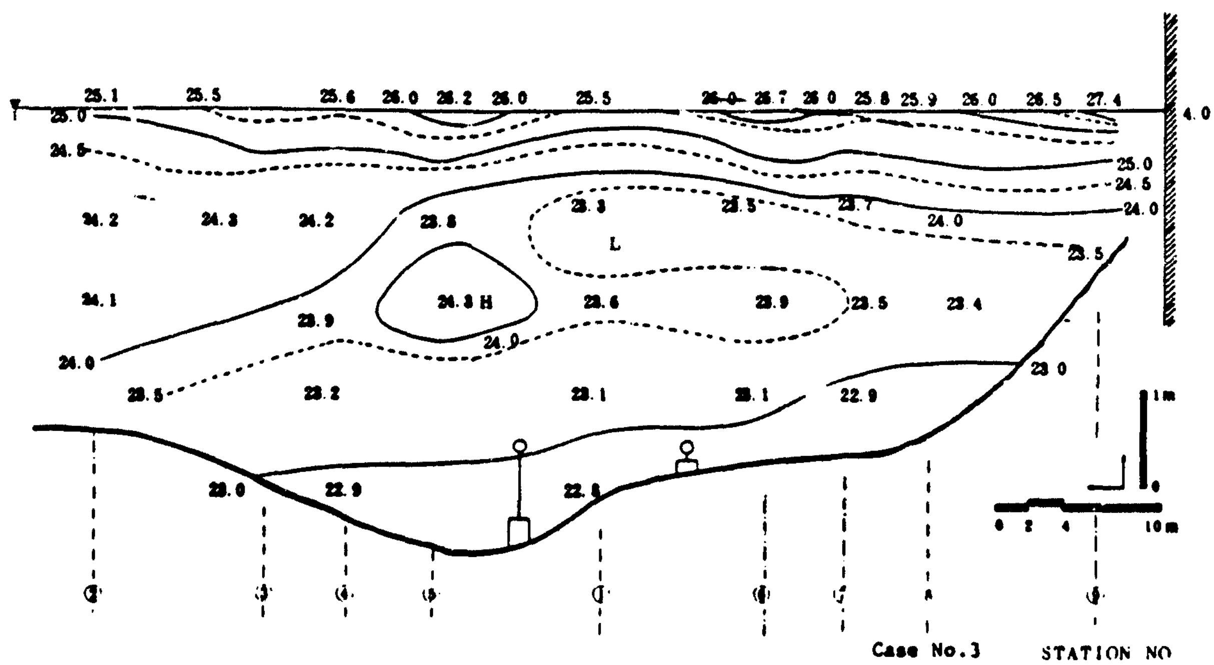

Figure 13. Sectional distribution of water temperature -A-A section just prior to aeration (units are in degrees Centigrade)

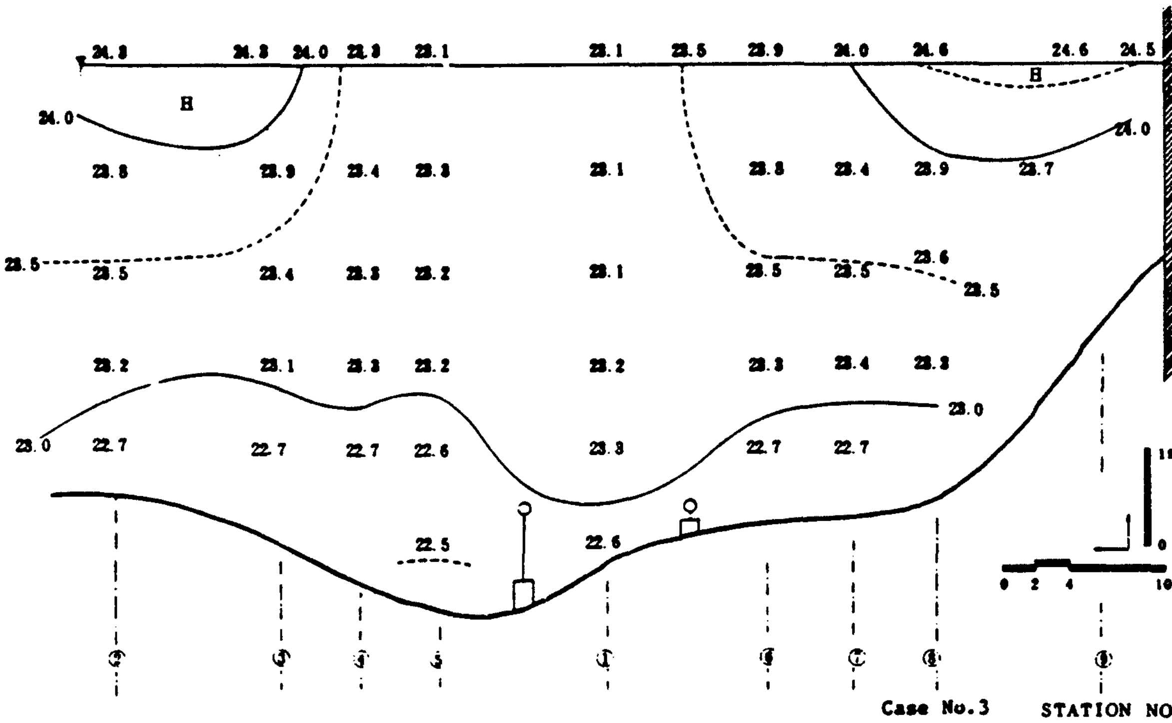

Figure 14. Sectional distribution of water temperature -A-A section 6 hr after aeration began (units are in degrees Centigrade)

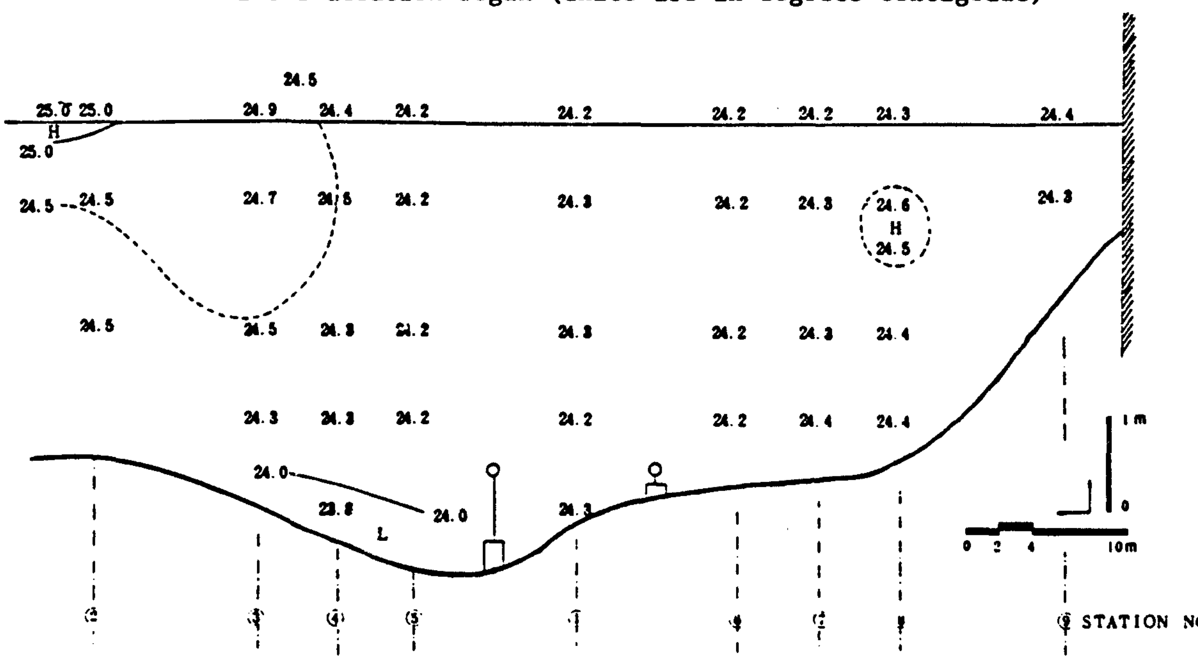

Figure 15. Sectional distribution of water temperature -A-A section 24 hr after aeration began (units are in degrees centigrade)

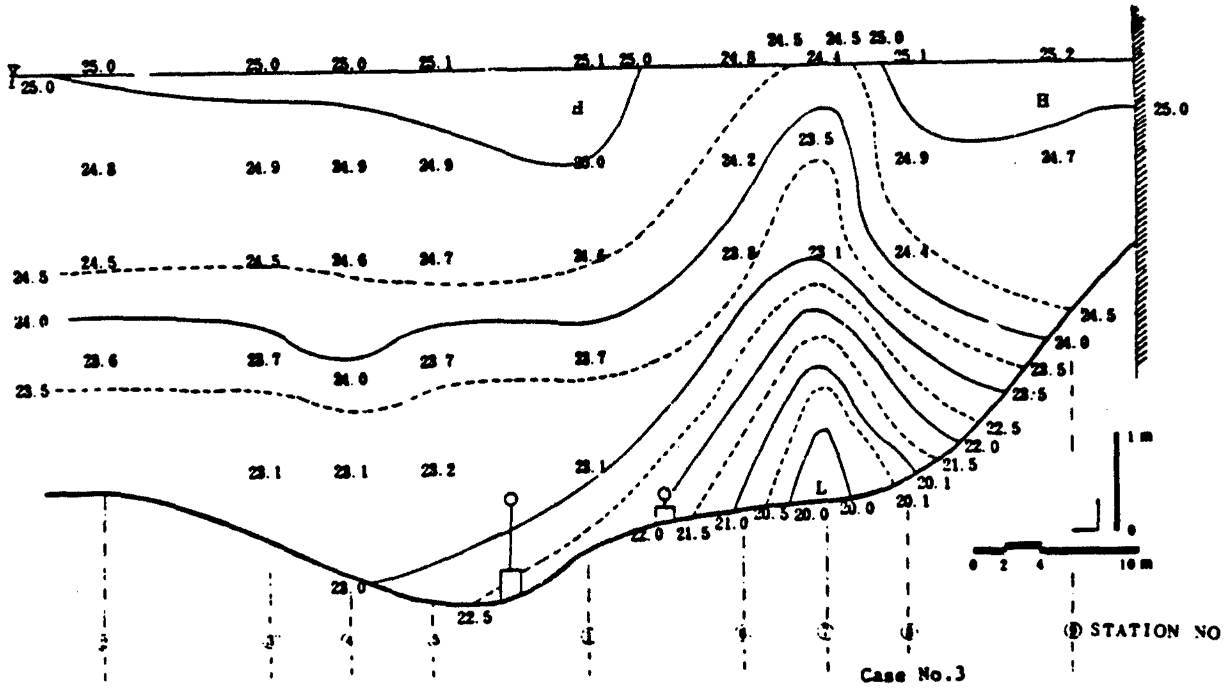

Figure 16. Sectional distribution of water temperature -A-A section 6 hr after aeration ceased (units are in degrees Centigrade)

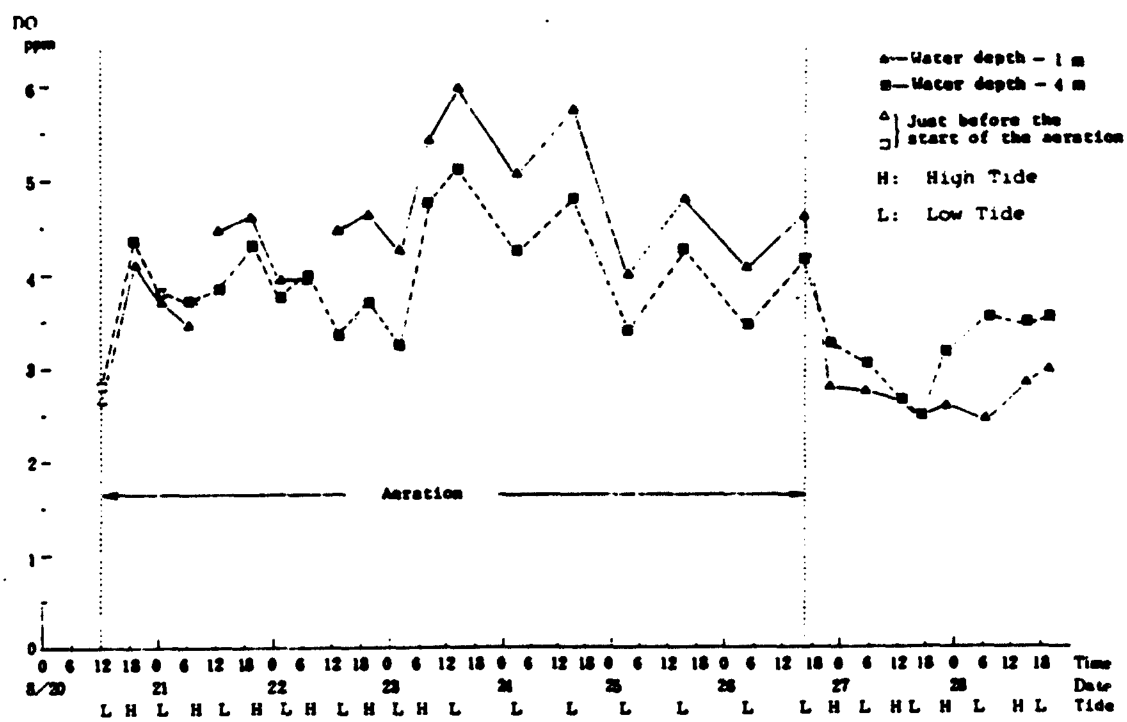

Figure 17. Comparison of dissolved oxygen between the upper and lower layers

Decreases of organic matter due to their decomposition and decreases of nutrient salts due to their oxidation were also recognized (Figure 18).

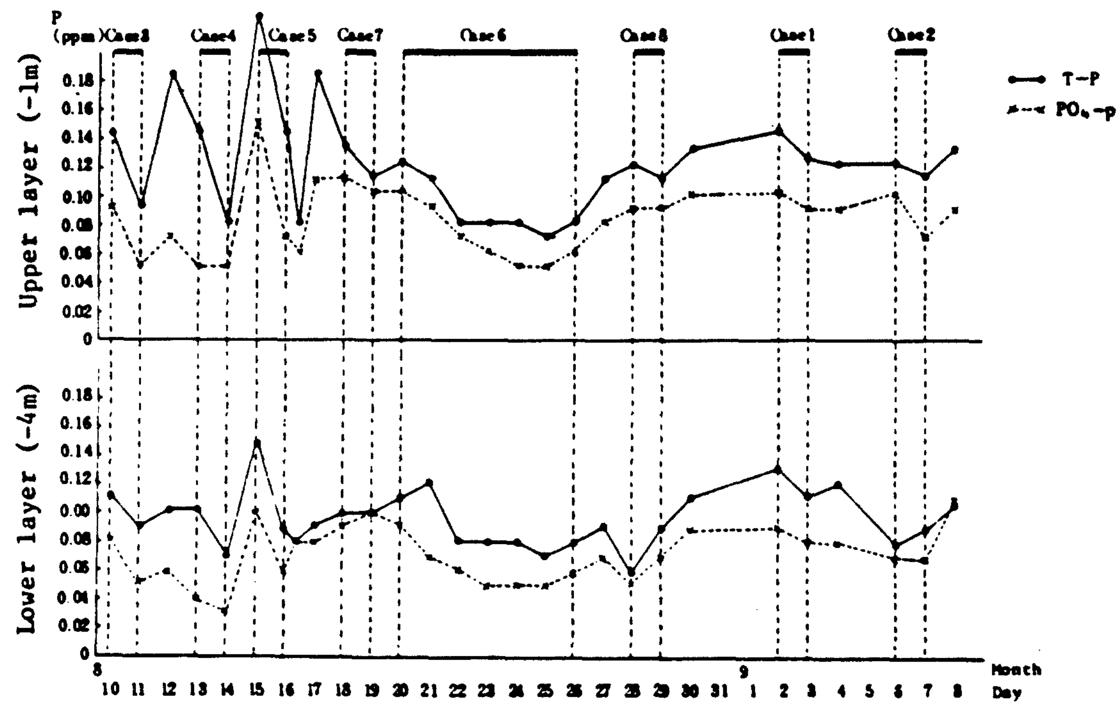

Figure 18. Change of total phosphorus (T-P) and phosphate phosphorus (PO_4-P) during the experiment (station 2)

CONCLUSIONS

It has been shown that aeration can be an effective method in improving the marine environment. However, more detailed studies and refinement of the method are needed. Studies are needed on the effects of a system in which several types of air tubes are combined and operated in a wider sea area, the effects of a longer operating time, the effects of intermittent operation, and the effects of differing air rates.

Furthermore, the cost performance of the aeration method needs to be compared with that of alternative measures. Possible alternative measures will include methods to reduce the release of COD, etc., from the sea bottom such as sediment dredging and covering the sea bottom with a clean sand layer, and methods to promote replacement of eutrophic seawater with oxygenated seawater by pumps or other means.

HYPOLIMNETIC OXYGEN DEFICIT IN A EUTROPHIC LAKE AND THE ROLE OF SEDIMENT OXYGEN DEMAND

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ABSTRACT

Lake surveys and in situ experiments were conducted to study the hypolimnetic oxygen deficit in a eutrophic lake, Lake Yunoko. A mathematical model was developed to estimate the dissolved oxygen budget in the lake. Production of oxygen by photosynthesis of phytoplankton, consumption by respiration of microorganisms, sediment oxygen demand, and oxygen transfer by eddy diffusion and reaeration at the surface of water were taken into consideration. It was shown from the budget that sediment oxygen demand plays an important role in the first stage of the hypolimnetic oxygen deficit in summer; i.e., the oxygen produced by photosynthesis was not transferred into the hypolimnion and the contribution of sediment oxygen demand was as large as that of the consumption in water. Restoration techniques for the oxygen deficit such as management of bottom sediment and control of phytoplankton production were discussed. The management of bottom sediment was shown to be an effective way to control the hypolimnetic oxygen deficit in Lake Yunoko.

INTRODUCTION

It is well known that the hypolimnetic oxygen deficit during summer stratification is frequently observed in dimictic and eutrophic lakes and reservoirs (1). The deficit causes release of phosphorus, manganese, and/or iron from the sediments (2). Released phosphorus may enhance primary production in the overlying water. High concentrations of manganese and/or iron may disable the direct use of the water for water works and the construction and operation of water treatment processes for the removal of these ions increase the cost of water works. The deficit also damages aquatic habitats.

Major factors to control dissolved oxygen (DO) concentration in water bodies are oxygen production by photosynthesis and oxygen consumption by respiration and/or sediment oxygen demand (SOD). Physical processes such as

reaeration at the water surface and vertical transport of oxygen by diffusion and/or convection are also important factors to determine vertical profiles in dissolved oxygen concentration in water, hence the hypolimnetic oxygen deficit.

Although there have been many studies on each process mentioned above, few comprehensive studies have been presented (3-9). Lake restoration projects would be necessary to cope with the deficit in DO in the hypolimnion (10). There would be direct measures, however, to control DO levels. Probably, those measures will be more efficient, i.e. economical and prompt, than general measures for eutrophication control.

The purpose of this study is to assess the contribution of sediment oxygen demand to vertical DO profiles in a eutrophic lake. Each major process was measured in situ. A mathematical model is presented to calculate DO budget and to assess the contribution of SOD to the budget and to the vertical profiles of DO in the lake. Also, techniques aiming at control of the hypolimnetic oxygen deficit were assessed through numerical simulations by the model. The lake in this study is Lake Yunoko (surface area = 0.33 km^2, maximum depth = 12.5 m). The period studied was the first stage (3 June to 9 June) of the hypolimnetic oxygen deficit.

MATHEMATICAL MODEL

Construction and Assumptions

A water column 11.6 m deep was divided into 12 layers at 1-m intervals except for the deepest layer (0.6 m). Dissolved oxygen concentration, C_i ($g \cdot m^{-3}$, i = 1-12), was defined at each layer as a state variable. The control variables are suspended solid concentration, S ($g \cdot m^{-3}$), light intensity outdoors, I_0 ($\mu Ein \cdot m^{-2} \cdot hr^{-1}$) and water temperature, θ (°C).

Assumptions used to construct and solve the model equations were as follows:

a. Horizontal distribution in DO values is negligibly small compared with the vertical distribution.

b. Reaeration and vertical eddy diffusion coefficients are constant throughout the period studied.

A system of equations for the model is shown in Table 1. All terms are defined in the nomenclature on page 38.

Values of Parameters

Values of parameters and empirical coefficients related to photosynthesis and respiration in water and SOD were estimated by in situ experiments at Lake Yunoko conducted during the study period.

TABLE 1. SYSTEM EQUATIONS FOR THE MATHEMATICAL MODEL

$$\frac{dC_1}{dt} = -R_1 + P_1 + (C^* - C_1)\frac{D^*}{H_1} + \frac{(C_2 - C_1)}{\left(\frac{H_1 + H_2}{2}\right)}\frac{D_1}{H_1} \qquad (1a)$$

$$\frac{dC_i}{dt} = -R_i + P_i + \frac{(C_{i-1} - C_i)}{\left(\frac{H_{i-1} + H_i}{2}\right)} + \frac{D_{i-1}}{H_i} + \frac{(C_{i+1} - C_i)}{\left(\frac{H_i + H_{i+1}}{2}\right)}\frac{D_i}{H_i} \quad \text{for } i = 2\text{–}11 \qquad (1b)$$

$$\frac{dC_{12}}{dt} = -R_{12} + P_{12} + \frac{(C_{11} - C_{12})}{\left(\frac{H_{11} + H_{12}}{2}\right)}\frac{D_{11}}{H_{12}} - C_{12}\frac{k}{H_{12}} \qquad (1c)$$

Vertical eddy diffusion coefficients between layers were estimated based on the heat balance equations (11):

$$W\rho \int_{z}^{z_{max}} \left(\frac{\partial\theta}{\partial z}\right) dz = -W\rho D_z \left(\frac{\partial\theta}{\partial z}\right)_z \qquad (2)$$

Consecutive measurements of water temperature at the indicated depth intervals were conducted and D_z values at the interfaces of two layers were estimated by solving Equation 2. No direct measurements for the reaeration coefficient (oxygen transfer at the interface between air and water) were tried in this study. Values reported from the Water Research Centre (U.K.) ranged from 0.26 to 0.67 $m \cdot day^{-1}$ (12). The reported average value, 0.55 $m \cdot day^{-1}$ (= 0.023 $m \cdot hr^{-1}$; see Table 2), was adopted for the following simulation.

TABLE 2. VERTICAL EDDY DIFFUSION COEFFICIENTS AND REAERATION COEFFICIENT

	D	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}
	$\times 10^{-2} m^2 \cdot hr^{-1}$											
Estimated	2.3*	3.3	4.0	3.3	2.6	0.9	1.6	1.0	0.6	1.4	0.9	0.8
Calibrated		6.7	6.7	6.3								

* A value reported from the Water Research Center, U. K., for still waters.

Procedure

Obviously, the system equations cannot be solved analytically. A numerical procedure by the Runge-Kutta-Gill method was employed to solve the equations (HITAC M-150, Computer Center, The National Institute for Environmental Studies). The initial condition for the computation was taken from the observed DO values along the depth intervals on 3 June. Among control variables, suspended solids (SS) and water temperature were monitored along depth intervals once per day throughout the simulation. Light intensity outdoors was monitored continuously by a illuminometer. Light intensity underwater was calculated following Lambert-Beer's law. The extinction coefficients were determined from vertical distribution of SS values. Except for light intensity outdoors, the control variables were monitored only once per day. Then, the requisite values of the control variables during the calculation were estimated by interpolation with Lagrange's algorithm.

EXPERIMENTAL BACKGROUND

Hypolimnetic Oxygen Deficit in Lake Yunoko

Limnological surveys in Lake Yunoko (located in Nikko National Park, ca. 100 km north of Tokyo) were conducted weekly from April to August in 1981. Intensive daily surveys from 2 June to 9 June were also conducted. This period was the first stage of the thermal stratification in summer. Vertical profiles of DO concentration, SS concentration, underwater light intensity, I ($\mu Ein \cdot m^{-2} \cdot hr^{-1}$), and water temperature were monitored at the lake center (depth = 11.6 m).

Respiration and Photosynthesis

The rates of oxygen consumption in water by the respiration of phytoplankton, bacteria, and other microorganisms and the oxygen production by the photosynthesis of phytoplankton were measured in situ by the light-dark bottle method. Several dark bottles were submerged at 0, 1, 2, 4, 8, 10, and 11 m and sampled every 24 hr for DO determination. Light bottles were also submerged at 0, 1, and 2 m and sampled every 2 or 4 hr for DO determination. Both rates were converted into the specific rates per 1 g of SS by the simultaneously determined SS values.

Sediment Oxygen Demand

Submerged chambers shown in Figure 1 were set on the lake bottom near the lake center (13). Bottom sediments of an area 0.4 m by 0.4 m (0.16 m^2) with overlying water 0.15 m deep (0.024 m^3) were enclosed by the acrylic chamber. A small amount (ca. 120 ml) of water was withdrawn from the chamber once or twice per day through a sampling tube (2 mm I.D. × 15 m) by a syringe to determine DO values in the enclosed water. The syringe was also used to homogenize the water in the chamber by repeated injections and withdrawals of the water prior to the sampling. The rate of SOD was calculated from the rate of decrease in DO in the water enclosed by the chamber.

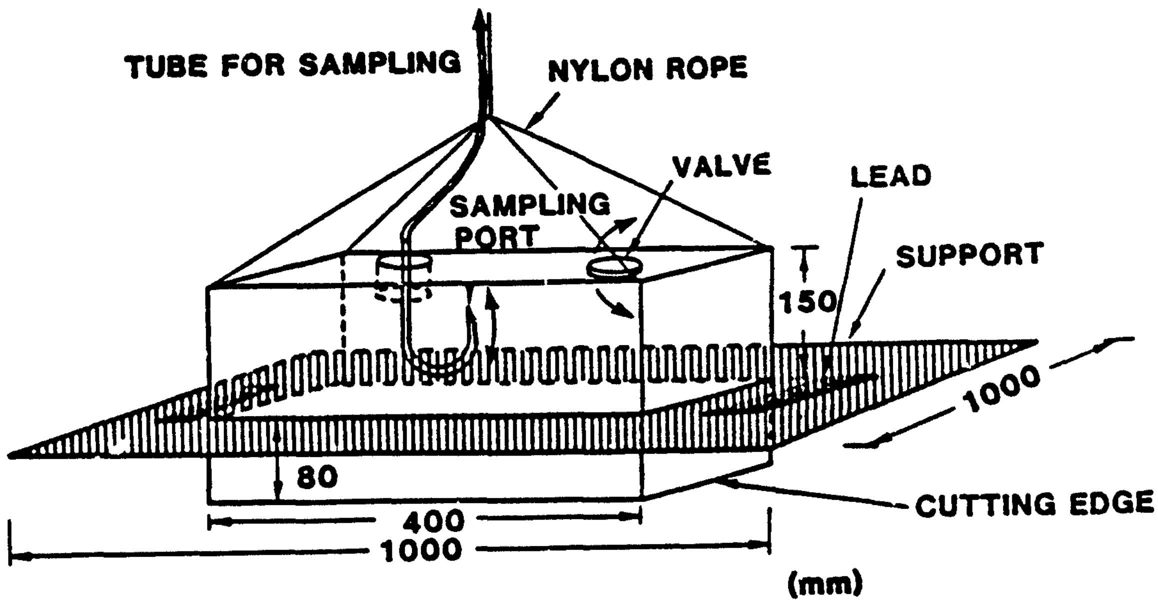

Figure 1. Schematic diagram of a submerged chamber

RESULTS AND DISCUSSION

Vertical DO Profiles

Vertical distribution of DO and water temperature from 3 June to 9 June 1981 are shown in Figure 2. Both the values of DO and water temperature along the depth were uniform on 26 May indicating the spring circulation period (not shown in Figure 2). It is clear that the period shown in the figure was the first stage of the thermal stratification in summer. Actually, the difference in the water temperature between the surface and deep (deeper than 4 m) layers increased with time after 3 June. Along with the stratification in water temperature, the stratification in DO and the oxygen deficit in the bottom layers are noted. Especially in the deepest layer, DO decreased from 9 $g \cdot m^{-3}$ down to less than 4 $g \cdot m^{-3}$ in a week.

Rate of Oxygen Consumption in Water

The specific (per g SS) rate of oxygen consumption in water, R ($g\ O_2 \cdot g^{-1}\ SS \cdot hr^{-1}$) was assumed to be a function of both water temperature and DO concentration (14). Figure 3 shows the dependence of the consumption rates on water temperature. It must be noted that all the incubations shown in the figure to determine the rates were not limited by DO concentration. Assuming that the dependence on DO could be expressed by Monod's equation (12, 15,16), the following relationship was obtained:

$$R = (0.0072 \cdot \theta - 0.0068) \cdot S \frac{C}{0.25 + C} \qquad (3)$$

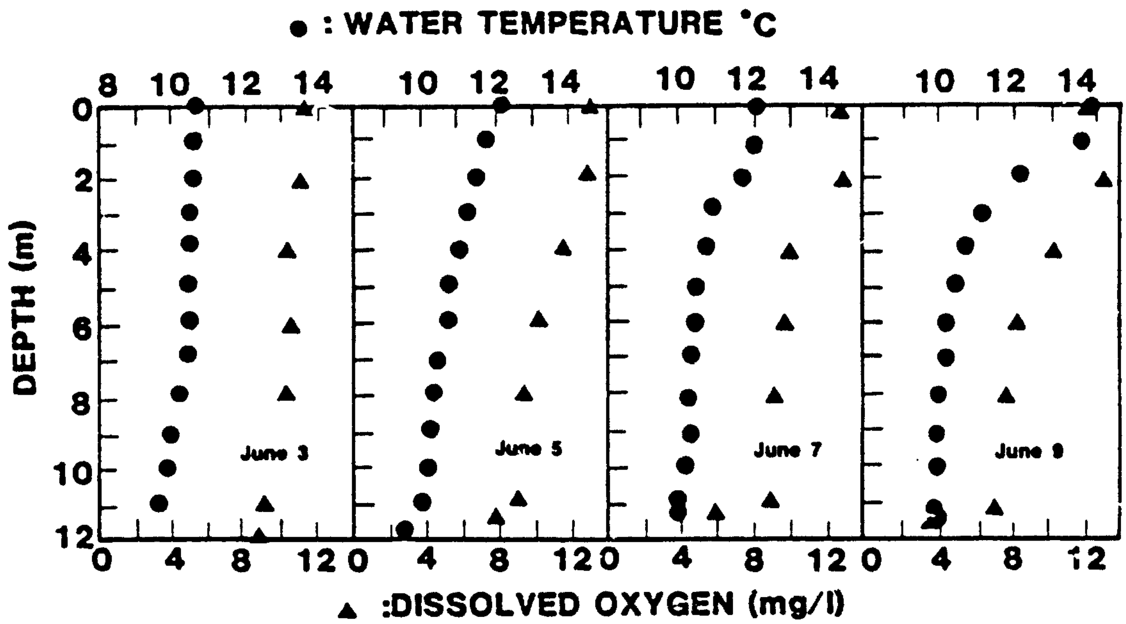

Figure 2. Dissolved oxygen concentration and water temperature along the depth intervals (3 June - 9 June 1981, Lake Yunoko)

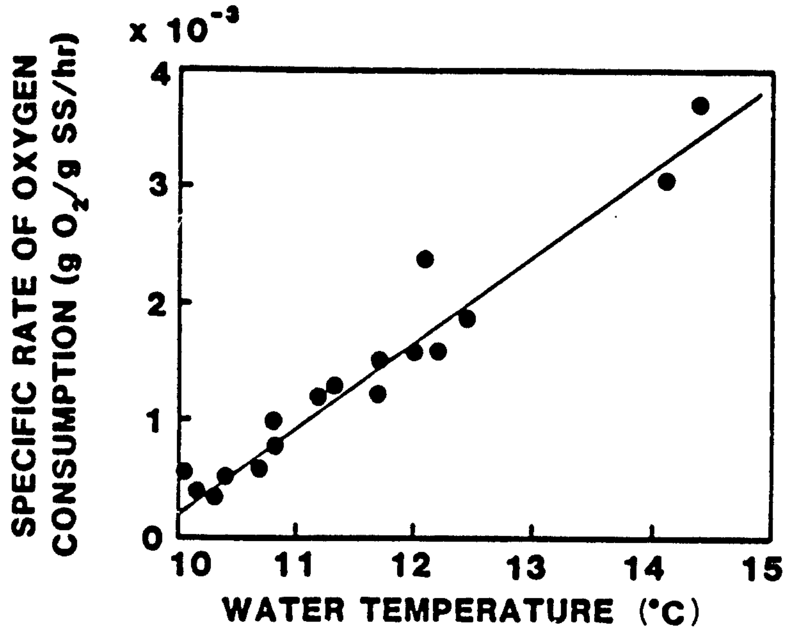

Figure 3. Specific rate of oxygen consumption as a function of water temperature

Rate of Oxygen Production in Water

The specific rate of oxygen production in water by the photosynthesis of phytoplankton, P ($g\ O_2 \cdot g^{-1} SS \cdot hr^{-1}$), was represented by Blackman's equation as a function of light intensity, I ($\mu Ein \cdot m^{-2} \cdot hr^{-1}$) (see Figure 4)(17):

$$P = 2.236 \times 10^{-8} \cdot I \qquad \text{for } I < 30 \times 10^5 \quad \mu Ein \cdot m^{-2} \cdot hr^{-1} \tag{4}$$

or

$$= 0.072 \qquad \text{for } I \geq 30 \times 10^5 \quad \mu Ein \cdot m^{-2} \cdot hr^{-1}$$

The effect of water temperature on P was disregarded in this study because enough reliable data to estimate the effect of temperature on the rates could not be obtained.

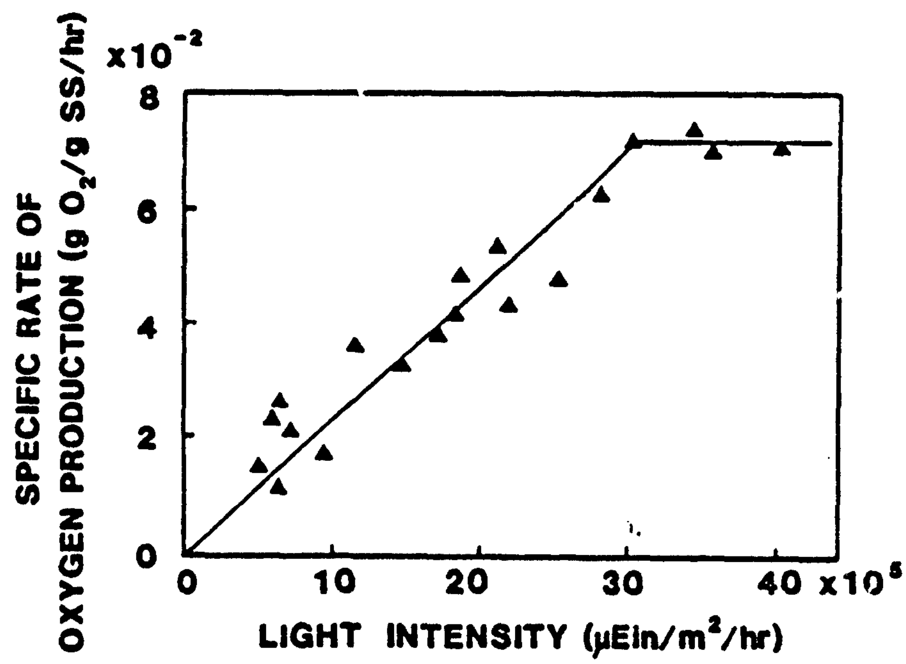

Figure 4. Specific rate of oxygen production as a function of light intensity

Sediment Oxygen Demand

The rate of decrease in DO in the water enclosed by the submerged chamber, V_c (m^3), should be proportional to the rate of oxygen consumption by the enclosed bottom sediment, A_c (m^2). Also, the rate was assumed to be proportional with dissolved oxygen concentration in the water, C ($g\ O_2 \cdot m^{-3}$). The rate, dCV/dt, was then expressed by:

$$\frac{dCVc}{dt} = -A_c kC \quad (5)$$

Giving the initial value (at $t = 0$) of C as $_0C$, an analytical solution to Equation 5 could be obtained as follows:

$$\ln C = -\frac{A_c}{V_c} kt + \ln C_0 \quad (6)$$

Then ln C could be plotted against as shown in Figure 5. The solid line in Figure 5 was secured by the method of least squares and gave the value of the rate constant for SOD, k, as follows:

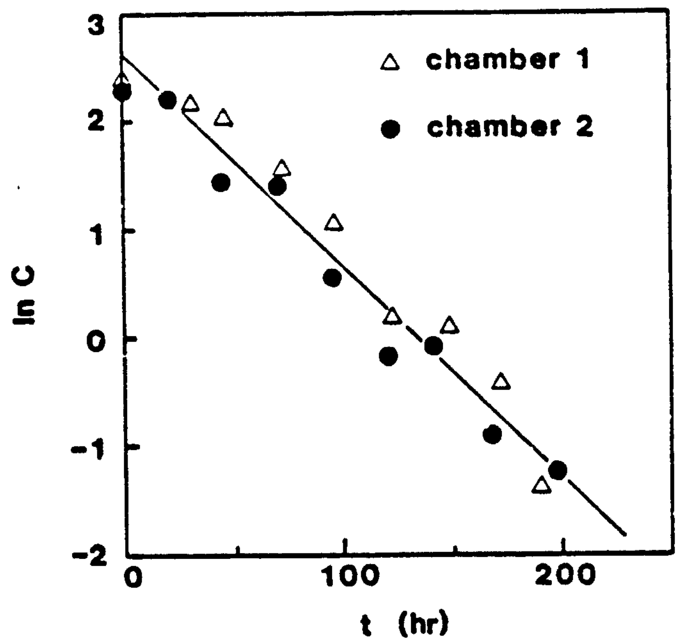

Figure 5. Decrease in DO in the chamber (ln C) with time by SOD

$$-\frac{A_c}{V_c} k = -1.64 \times 10^{-2}, \text{ then}$$

$$k = \frac{0.024}{0.16} \times 1.64 \times 10^{-2} = 2.5 \times 10^{-3} m \cdot hr^{-1}$$

Vertical Eddy Diffusion Coefficients

Vertical eddy diffusion coefficients, D ($m^2 \cdot hr^{-1}$:i = 1-12), were estimated from Equation 2 for each interface of the two layers. The values estimated are summarized in Table 2. Diurnal variation in water temperature at the

surface layers made the determination of D_i values from Equation 2 difficult. It must be noted, therefore, that the D_i values near the surface may be less reliable than those for deeper layers.

Calibration

Although calculated DO values (Equation 1) at depths greater than 3 m were in agreement with the observed values, those values near the water surface deviated from the observed values if the eddy diffusion coefficients in Table 2 were used (not shown here). The model was then calibrated for the eddy diffusion coefficients of surface layers, i.e. D_1, D_2, and D_3. As mentioned above, these values were relatively unreliable estimates. The calibrated values of D_i ($i = 1-3$) ranged from 1.5 to 2 times as large as the originals as shown in Table 2. The calculated DO values after calibration were in good agreement with the observation as shown in Figure 6 (see the control for calculated values and observed data in the figure).

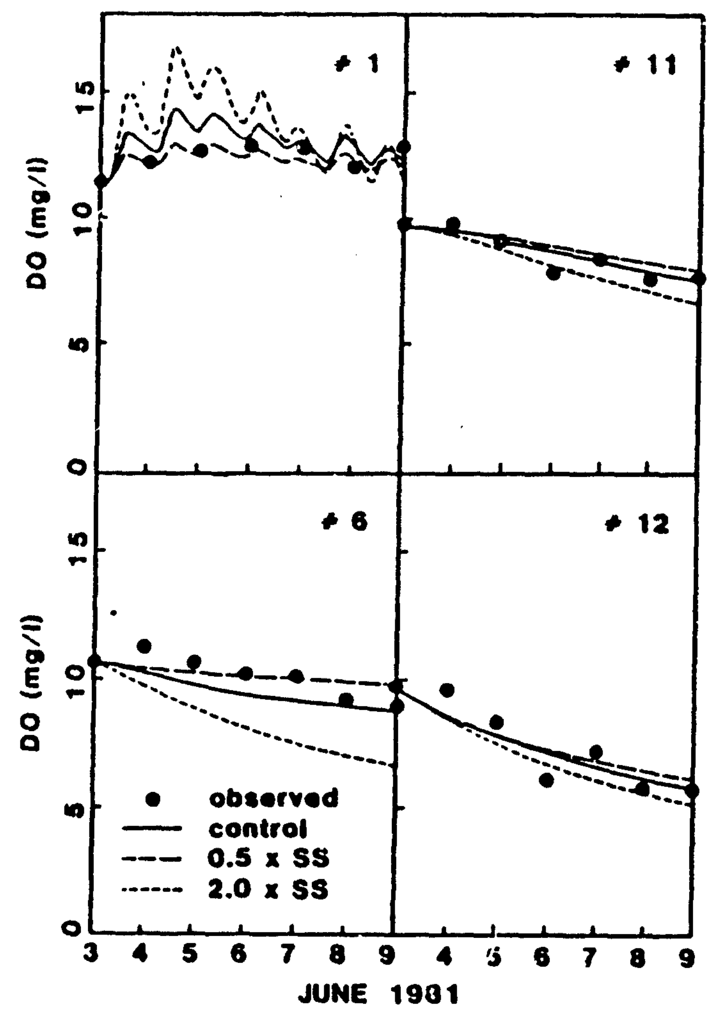

Figure 6. Effects of change in SS values on DO profiles

Oxygen Budget

An oxygen budget calculated from the calibrated model is shown in Figure 7. The largest change in DO value (ΔDO) was noted at the bottom layer (i = 12). Values in the figure show the contribution of each factor, i.e. the average (between 3 and 9 June) rate of change per day in DO values of the layer expected by the contribution of the factor.

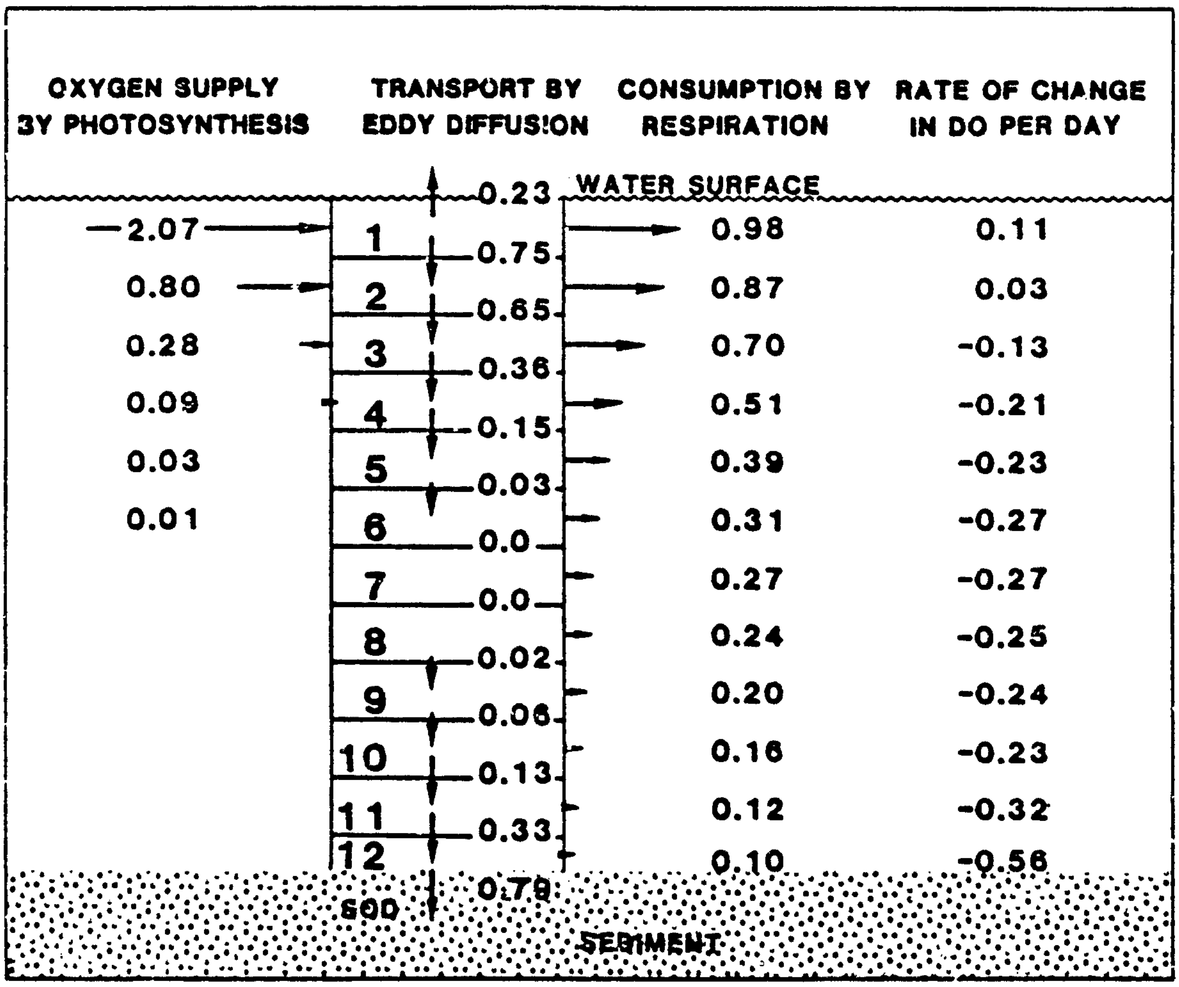

Figure 7. Dissolved oxygen budget in Lake Yunoko (3-9 June 1981)

Oxygen supply by photosynthesis was largest at the surface layer (i = 1) and decreased with depth. The photosynthetic supply was negligible in layers greater than 5 m (i $\geq$ 6). The rate of oxygen consumption also decreased with depth. The rate of consumption in the bottom layer was only one tenth of that in the surface layer. Instead, the SOD played a remarkable role on the largest deficit in DO at the bottom layer (i = 12).

Vertical eddy diffusion transferred oxygen from surface layers to deeper layers. The oxygen produced in the surface (photic) layers was transferred downward until the sixth layer. However, the amount transferred decreased with depth and no vertical transfer was noted between layers six and seven. Therefore, the oxygen supply by photosynthesis into the water column was effective in maintaining DO levels only in the upper layers ($i = 1$-6). Contrary to the upper layers, the amount of transfer increased with depth in the hypolimnion ($i = 8$-12). The transfer compensated for the large requirement of oxygen by the sediment and decreased DO levels in the hypolimnion.

Restoration Techniques for the Hypolimnetic Oxygen Deficit

Regardless of the actual techniques undertaken (10), the effects of the decrease or increase in SS values on the deficit were assessed. Note that SS in this study corresponds to the phytoplankton production in the lake. Out of several simulation runs where the SS values were changed from 0.01 to 5 times as large as the observed values along the depth intervals, the results of runs with 0.5 or 2 times present SS values are shown in Figure 6. The control in the figure corresponds to the case for observed SS values. Although a relatively rapid decrease in DO was noted at the sixth layer (5-6 m), if SS values were assumed to double, little differences in DO were noted in the bottom layers ($i = 11, 12$). Similarly, the decrease in SS values ($\times 0.5$) showed little differences in DO profiles of the bottom layers. Polak (7) and Schnoor (9) reported independently that oxygen consumption in water was the major factor for the hypolimnetic oxygen deficit and the role of SOD was small. Contrary to the lakes studied by these authors, SS values had little effect on the first stage of the hypolimnetic oxygen deficit in summer in Lake Yunoko.

The effects of SOD on the hypolimnetic oxygen deficit were studied by simulation runs where the rate constant, k (Equation 5), was changed from 0 to 5 times as large as the estimated value. Figure 8 shows calculated DO values where the k value was 0.1 or 2 times the original. It is quite natural that DO values in the upper layers ($i = 1$-6) did not change. DO values in the bottom layers (see $i = 11$ and 12 in the figure), however, were significantly affected by the change in k values; i.e. the decrease ($\times 0.1$) in the rate of SOD significantly improved hypolimnetic oxygen deficit and the increase ($\times 2.0$) enhanced the deficit.

CONCLUSIONS

Based on the results obtained from lake surveys and in situ experiments at the first stage of thermal stratification and analyses of DO profiles by a simulation model, the following conclusions can be drawn:

a. The SOD rate demand was determined by in situ submerged chambers. The rate per unit area was in proportion to DO concentration.

b. Rates of oxygen consumption in water decreased along with depth. The rate in the bottom layer was only one tenth of that in the surface. Rapid decrease in DO at the bottom layer was found to be due to high SOD rate.

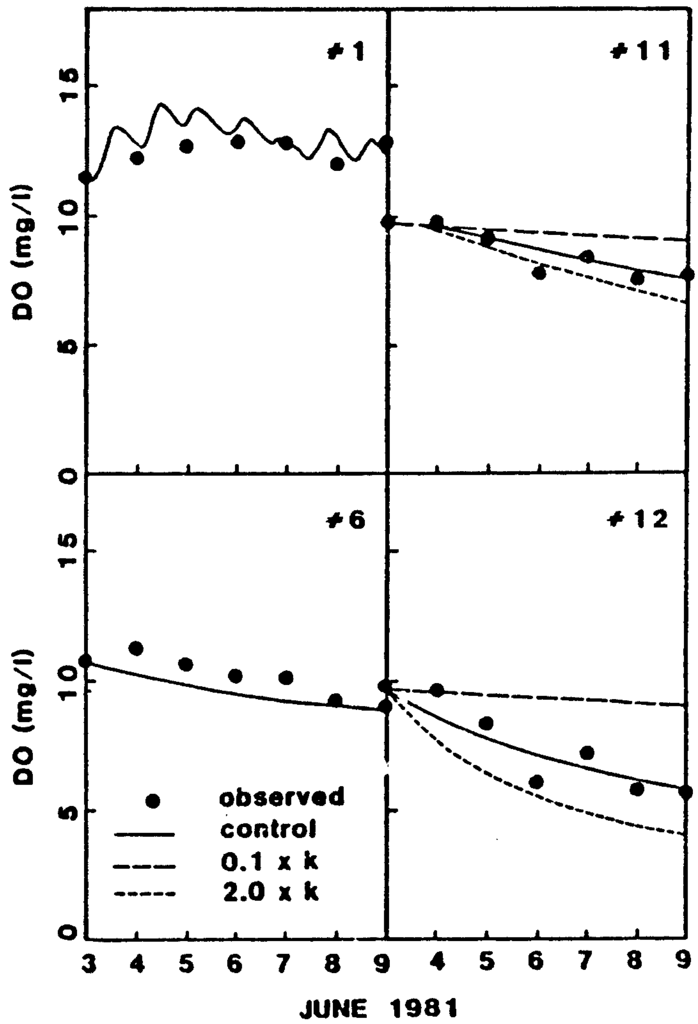

Figure 8. Effects of the change in the rate constant of SOD on DO profiles

c. Although oxygen produced by photosynthesis was transferred by the eddy diffusion into deeper layers, it disappeared at around the middle layers and did not compensate for hypolimnetic oxygen deficiency.

d. Remarkable restoration from the hypolimnetic oxygen deficit was not expected by the control of phytoplankton production. The control of SOD was found to be an effective restoration technique in Lake Yunuko.

NOMENCLATURE

A_c bottom area of submerged chamber, m^2

C, C_i dissolved oxygen concentration, $g \cdot m^{-3}$

C^*	saturation concentration of dissolved oxygen, $g \cdot m^{-3}$
D_i, D_z	eddy diffusion coefficient, $m^2 \cdot hr^{-1}$
D^*	reaeration coefficient, $m \cdot hr^{-1}$
H_i	thickness of layer, m
I, I_0	light intensity underwater and outdoors, $\mu Ein \cdot m^{-2} \cdot hr^{-1}$
k	rate constant for sediment oxygen demand, $m \cdot hr^{-1}$
P	specific rate of oxygen production, $g\ O_2 \cdot g^{-1}\ SS \cdot hr^{-1}$
R	specific rate of oxygen consumption, $g\ O_2 \cdot g^{-1} \cdot SS \cdot hr^{-1}$
S	suspended solid concentration, $g \cdot m^{-1}$
t	time, hr
V_c	volume of submerged chamber, m^3
W	specific heat of water, $cal \cdot g^{-1} \cdot {}^\circ C^{-1}$
z, z_{max}	depth and maximum depth, m
ϵ	water temperature, °C
ρ	water density, $kg \cdot m^{-3}$

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THEORETICAL CONSIDERATIONS OF GRAVITY DEWATERING OF DREDGED MATERIAL THROUGH THE BOTTOM OF A CONTAINMENT AREA

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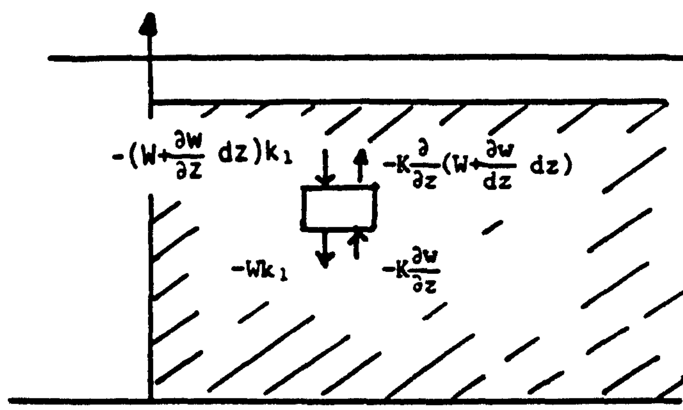
ABSTRACT

A pilot study utilizing short-term dewatering basins for dredged material was performed adjacent to a dredging site at Lake Suwa. An outline of this test was reported in this meeting by Nakamura. The study was based on the newly incorporated idea of dredged material dewatering by gravity drainage. The test not only had good results, but also created interesting suggestions from the soil mechanics point of view.

This paper deals with the theoretical considerations of these test results, in which dewatering behavior is discussed from various points of view.

FUNDAMENTAL EQUATION OF WATER MOVEMENT IN SOIL

Considering a small element dx dy dz inside a nondeformable material, we derive an expression of mass continuity for water as follows:



$$\frac{dw}{dt} = -k_1\frac{dw}{dz} + K\frac{d^2w}{dz^2} \tag{1}$$

where

w = water content of dredged material

k_1 = vertical permeability coefficient of dredged material

K = diffusion coefficient of water particles in the vertical direction

We assume that the solution of Equation 1 is a separate function with respect to t and z:

$$w = T(t)\ S(z) \tag{2}$$

Putting this into Equation 1, we get

$$\frac{T'}{T} = \frac{-k_1 S' + KS''}{S} \tag{3}$$

Here both sides are put to $-n^2$,

$$\frac{T'}{T} = -n^2 \tag{4}$$

$$S'' - \frac{k_1}{K} S' + \frac{n^2}{K} S = 0 \tag{5}$$

where

t = time

T = time function

S = function of z

z = vertical axis (height)

S' = differentiation of S

S'' = secondary differentiation of S

n = exponent of reduction

Hence we have

$$T = C_1 e^{-n^2 t} \tag{6}$$

and

$$S(z) = C_2 e^{m_1 z} + C_3 e^{m_2 z} \tag{7}$$

$$m = \frac{k_1}{2K} \pm \sqrt{\frac{k_1}{2K} - \frac{n^2}{K}} \tag{8}$$

Finally the solution becomes

$$W = e^{-n^2 t}\left(C_1 e^{m_1 z} + C_2 e^{m_2 z}\right) \tag{9}$$

Equation 8 is rewritten as follows:

$$m = \frac{k_1}{2K}\left(1 \pm \sqrt{1 - \frac{4n^2 K}{k_1^2}}\right)$$

As the coefficient k_1 is very small, the term $\frac{4n^2 K}{k_1^2}$ is much larger than 1; that is, the value under $\sqrt{\ }$ is negative.

Putting here,

$$\alpha = \sqrt{\frac{4n^2 K}{k_1^2} - 1} \tag{10}$$

We have

$$m = \frac{k_1}{2K}\,(1 \pm i\alpha) \tag{11}$$

Using this, we readjust Equation 9:

$$W = e^{-n^2 t}\left[C_1 e^{\frac{k_1}{2K}(1+i\alpha)Z} + C_2 e^{\frac{k_1}{2K}(1-i\alpha)Z}\right]$$

$$= e^{-n^2 t + \frac{k_1}{2K} Z}\left(C_1 e^{i \frac{k_1}{2K} \alpha Z} + C_2 e^{-i\alpha \frac{k_1}{2K} Z}\right)$$

$$= e^{-n^2 t + \frac{k_1}{2K} Z}\left(C_3 \cos \frac{\alpha k_1}{2K} Z + C_4 \sin \frac{\alpha k_1}{2K} Z\right)$$

$$W = e^{-n^2 t + \frac{k_1}{2K} Z} A \sin\left(\frac{\alpha k_1}{2K} Z = a\right) \tag{12}$$

As a boundary condition we take

$$t = 0,\ Z = H,\ W = W_0$$

Then we have

$$A = W_0 e^{-\frac{k_1}{2K} H} \frac{1}{\sin\left(\frac{\alpha k_1}{2K} H + a\right)}$$

Hence Equation 12 becomes

$$W = W_0 e^{-n^2 t - \frac{k_1}{2K}(H-Z)} \frac{\sin\left(\frac{\alpha k_1}{2K} Z + a\right)}{\sin\left(\frac{\alpha k_1}{2K} H + a\right)} \tag{13}$$

From Equation 13 we can see that the water content decreases exponentially with respect to time and that it is distributed vertically in a function multiplied by exponential and sine curves.

Here (Figure 1) we consider the fluid continuity expression for a bottom drainage system.

$$\frac{\gamma s F H}{1 + e_0}\int_0^H \frac{W(t = 0)}{H}\,dz = \frac{\gamma s F(H - \Delta H)}{1 + e}\int_0^{H-\Delta H} \frac{w(t)}{H - \Delta H}\,dz + \int_0^t E\,dt + \int_0^t k_2 F\,dt \qquad (14)$$

where

F = cross-sectional area

H = initial depth of dredged material

e_0 = initial void ratio of dredged material

e = void ratio after t

γs = specific weight of dredged material

E = evaporation

k_2 = flux of fluid through the bottom filter

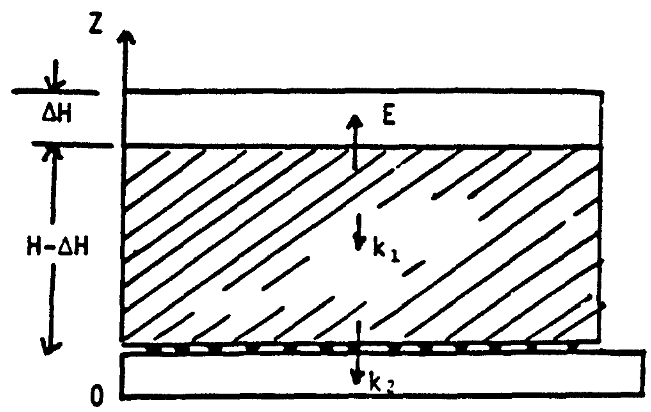


Figure 1. Bottom drainage system

Differentiating Equation 14, we have the following equation, with the assumption that $\frac{1 + e}{1 + e_0} = \frac{H - \Delta H}{H}$:

$$\frac{W_0 \gamma_w (-n^2) e^{-n^2 t}}{(1 + e_0)\left(1 - \frac{\Delta H}{H}\right)}\int_0^{H-\Delta H} e^{-\frac{k_1}{2K}(H-Z)}\,\frac{\sin\left(\frac{\alpha k_1}{2K} Z + a\right)}{\sin\left(\frac{\alpha k_1}{2K} H + a\right)}\,dz + E + k_2 = 0 \qquad (15)$$

If we can assume here,

$$E = E_0 e^{-n^2 t}$$

$$k = k_2(o) e^{-n^2 t}$$

We can obtain the value of n , as a constant independent of time:

$$n^2 = \frac{k_1 (E + k_2)\left(1 - \frac{\Delta H}{H}\right)(1 + e_0)(1 + \alpha^2) \sin\left(\frac{\alpha k_1}{2K} H + a\right)}{2W_0 \gamma s K - \beta} \tag{16}$$

$$\beta = e^{-\frac{k_1}{2K}\Delta H}\left\{\sin\left[\frac{k_1}{2K}(H - \Delta H) + a\right] - \alpha \cos\left[\frac{\alpha k_1}{2K}(H - \Delta H) + a\right]\right\} - e^{-\frac{k_1}{2K} H}(\sin a - \alpha \cos a) \tag{17}$$

From Equation 16 we find that the value of n^2 is proportional to the product $k_1(E + k_2)$; that is,

$$n^2 \propto k_1(E + k_2) \tag{18}$$

The reason that bottom drainage exhibits a very quick dewatering lies in this point (Figure 2).

From the test results, the values of n^2 are obtained as follows over an interval of 2 days:

	n^2
No. 2	0.226
No. 3	0.293
No. 1	0.079

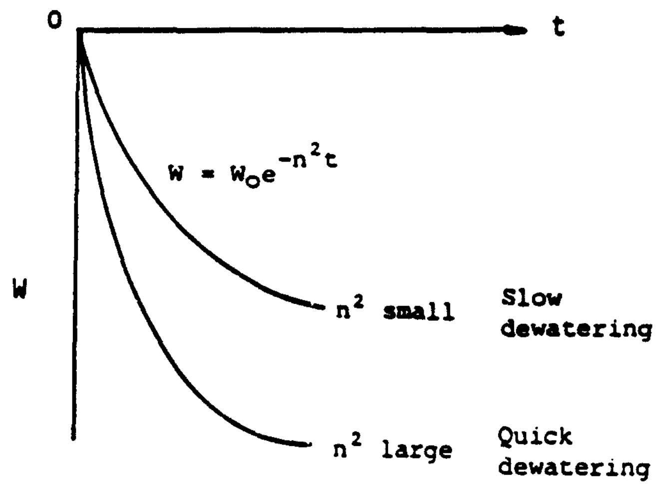


Figure 2. Reduction of water content

TIME-DEPENDENT CHANGE OF WATER CONTENT

The changes in the water content in ponds No. 1 and No. 2 are shown in Figure 3.

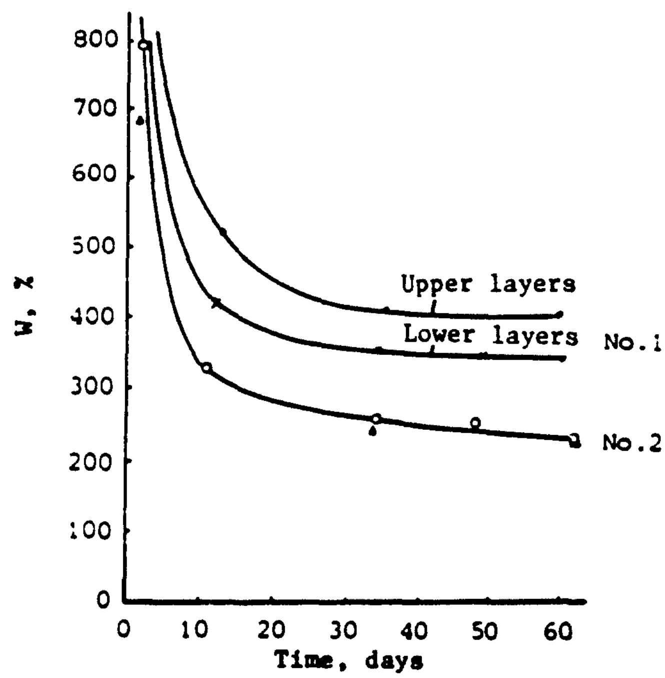


Figure 3. Change of water content

As the figure shows, the water content decreases rapidly at the beginning of the time interval and then slows after about 20 days. Therefore, the

time-change curve consists of two parts: rapidly decreasing and slowly convergent.

It is clear that the former part of the curve is exponential and of the form $e^{-n^2 t}$, which was derived in the first part of this paper. But with the decrease of water content, the weight of dredged material itself has an effect; that is, the solid particles become consolidated. In a consolidated state, Equation 1, which represents the movement of only water particles, is no longer valid.

In this phase we must account for the change in water content caused by consolidation. The hydraulic pressure of pore water is represented by the following equation derived by Terzaghi:

$$\frac{\partial U}{\partial t} = Cv \frac{\partial^2 U}{\partial Z^2} \qquad (19)$$

$$Cv = \frac{k_1 Es}{\gamma w} \qquad (20)$$

where

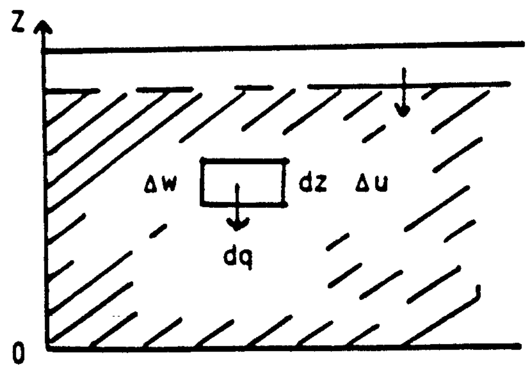
U = pore water pressure

Cv = coefficient of consolidation

k_1 = vertical permeability of dredged material

Es = elastic modulus of dredged material

γw = specific weight of water



The quantity of water per unit time per squeezed out element becomes

$$dq = \frac{k_1}{\gamma w} \frac{\partial^2 u}{\partial z^2} dx\ dy\ dz \tag{21}$$

As the decrease of water content ΔW is caused by this, then

$$- \frac{\partial W}{\partial t} \gamma s\ dxdydz = - \frac{k_1}{\gamma w} \frac{\partial^2 u}{\partial z^2} dx\ dy\ dz \tag{22}$$

Hence

$$\frac{\partial W}{\partial t} = \frac{k_1}{\gamma s \gamma w} \frac{\partial^2 u}{\partial z^2} \tag{23}$$

The solution of Equation 19 is as follows:

$$U = \sum_{i=1}^{\infty} \frac{2U_0}{i\pi} (1 - \cos i\pi)\left(\sin \frac{i\pi z}{2h}\right) e^{-\frac{1}{4} i^2 \pi^2 T} \tag{24}$$

where $$T = \text{time factor} = \frac{C_0 t}{h^2} \tag{25}$$

From Equation 2, we get the relationships between W and t

$$W = W_0 \sum_{i=1}^{\infty} e^{-\frac{i^2 \pi^2 Cv}{4h^2} t} \tag{26}$$

This gives a flat and convergent curve. In practice, we can replace it with a parabolic curve for brevity of calculation (Figure 4).

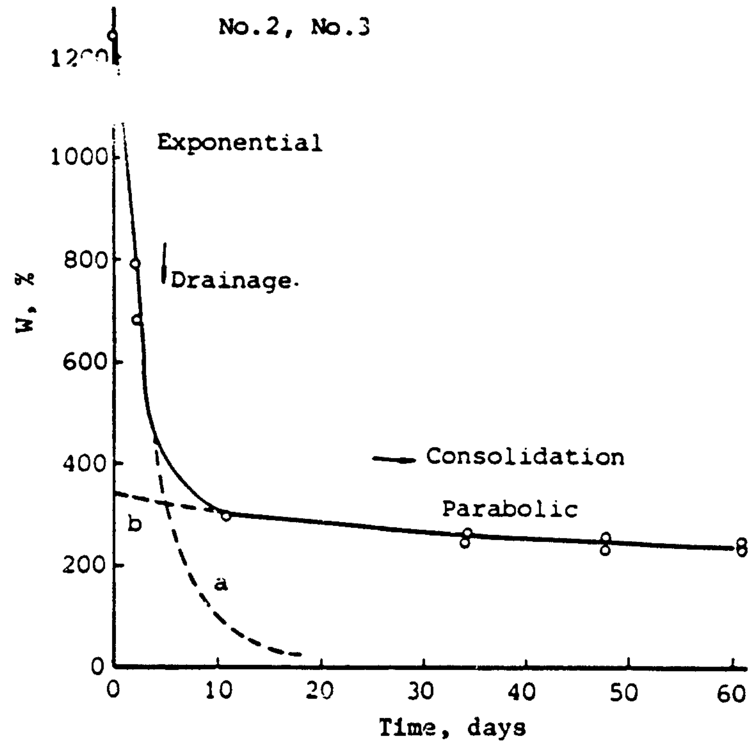


Figure 4. Change curve of water content consisting of two parts

Figure 4 shows the curve of water content which is assumed as a combination of exponential and parabolic functions. The latter is represented by the following equation:

$$W = Wd + \frac{(Td - t)^2}{2f} \tag{27}$$

where

Wd = water content at the point of convergence

Td = interval time to the point of convergence

f = figure index of parabola

Using this equation for the measured values, we obtain the following data for pond No. 2:

Wd = 251.4%

Td = 47.1 days

and for pond No. 3

$$Wd = 235.7\%$$

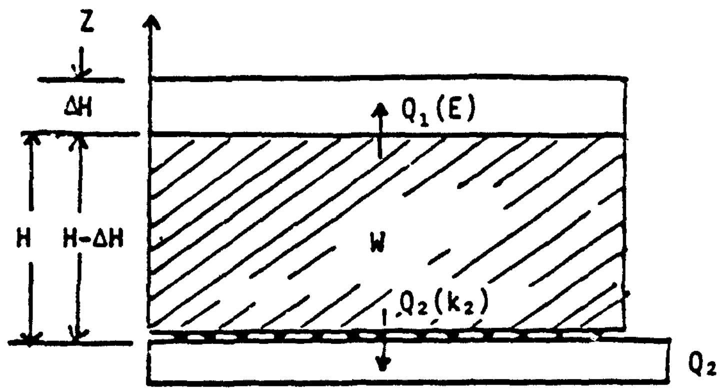
$$Td = 54.3 \text{ days}$$

As compared with these, the values of No. 1 become

$$Wd = 341\%$$

$$Td = 50.5 \text{ days}$$

BALANCE OF WATER QUALITIES IN POND



The above illustration is defined below:

Q_1 = water quantity which evaporates from the surface

Q_2 = water quantity which flows out from the bottom

W = average water content after t

H = initial thickness of dredged material

ΔH = settlement

k_2 = permeability of bottom filter

E = evaporation rate

Z = vertical axis

The equilibrium of water quantities is represented as follows:

$$\frac{\gamma s A H W_0}{1 + \frac{\gamma s}{\gamma w} W_0} = \frac{\gamma s A(H - \Delta H)}{1 + \frac{\gamma s}{\gamma} W} + Q_1 + Q_2 \tag{28}$$

where

A = cross-sectional area

W_0 = initial water content

γs = specific weight of solid

γw = specific weight of water

Since Q_1 and Q_2 are as follows:

$$Q_1 = \int_0^t EA_1 dt$$

$$Q_2 = \int_0^t EA_2 dt$$

We differentiate Equation 28

$$0 = \frac{\gamma s(1 + \gamma s W) - \gamma s W \cdot \gamma s}{(1 + \gamma s W)^2} \frac{dW}{dt} \left(1 - \frac{\Delta H}{H}\right) - \frac{\gamma s W}{1 + \gamma s W} \frac{d}{dt} \left(\frac{\Delta H}{H}\right) + E \frac{A_1/A}{H} + k_2 \frac{A_2/A}{H}$$

Hence we have

$$E \frac{A_1}{A} = H \left[\frac{\gamma s W}{1 + \gamma s W} \frac{d}{dt} \left(\frac{\Delta H}{H}\right) - \frac{\gamma s}{(1 + \gamma s W)^2} \left(1 - \frac{\Delta H}{H}\right) \frac{dW}{dt}\right] - k_2 \frac{A_2}{A}$$

If we put here

$$\theta = \frac{\gamma s W}{1 + \gamma s W} \frac{d}{dt} \left(\frac{\Delta H}{H}\right) - \left(1 - \frac{\Delta H}{H}\right) \frac{\gamma s}{(1 + \gamma s W)^2} \frac{dw}{dt}$$

We obtain

$$E\frac{A_1}{A} = \theta H - k_2\frac{A_1}{A} \tag{29}$$

From this, the value of E at each time point can be calculated, if θ and k_2 are known. An example of this calculation is indicated below:

$$t = 2 \text{ days}$$

$$\frac{\Delta H}{H} = 0.11$$

$$W_0 = 7.92$$

$$\frac{d}{dt}\left(\frac{\Delta H}{H}\right) = 0.055 \text{ 1/day (from figure)}$$

$$\frac{dW}{dt} = -2.265 \text{ 1/day (from figure)}$$

$$\theta = \frac{\gamma sW}{1+\gamma sW}\frac{d}{dt}\left(\frac{\Delta H}{H}\right) - \left(1 - \frac{\Delta H}{H}\right)\frac{\gamma s}{(1+\gamma sW)^2}\frac{dW}{dt}$$

$$= \frac{2.49 \times 7.92}{1 + 2.49 \times 7.92} \times 0.055 + (1 - 0.11)\frac{2.49}{(1 + 2.49 \times 7.92)^2} \times 2.265$$

$$= 0.0523 + 0.0117 = 0.064 \text{ 1/day}$$

From the quantity of water which flows out from the bottom during 2 days, we get

$$k_2 = \frac{6.7 \text{ m}^3\text{/day}}{75 \text{ m}^2} = 0.0893 \text{ m/day}$$

$$A = 120 \text{ m}^2$$

$$A_1 = 165\ m^2$$

$$A_2 = 75\ m^2$$

$$E \frac{165}{120} = 0.064 \times 126 - 8.93 \frac{75}{120}$$

$$E = 0.727(8.064 - 5.581) = 1.80 \text{ cm/day}$$

The change of evaporation obtained by the above-mentioned equation is indicated in Figure 5.

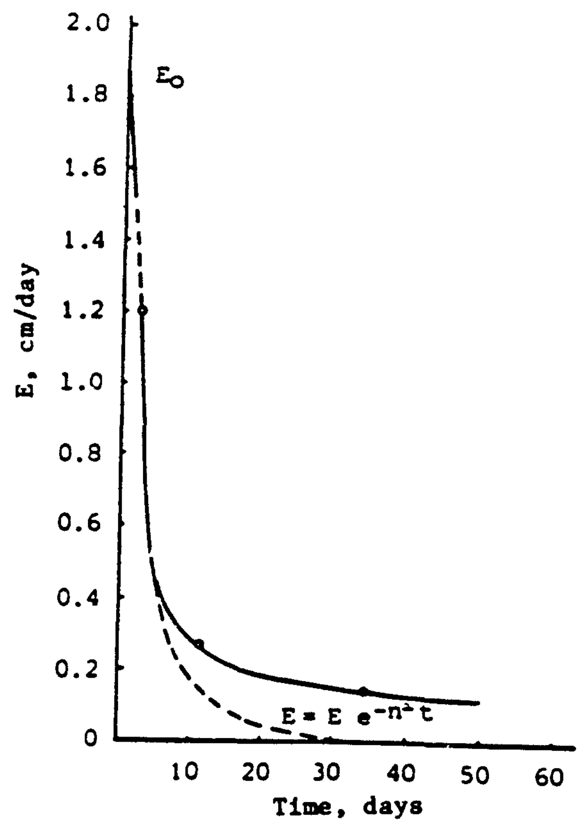
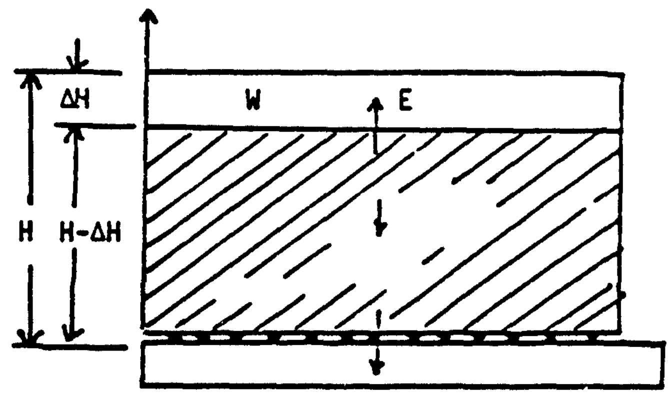


Figure 5. Evaporation

PERMEABILITY COEFFICIENT OF DREDGED MATERIAL



The terms used in the above illustration are as defined earlier plus the following:

Vw = water quantity inside settled volume

Vs = solid quantity inside settled volume

We have

$$Vw + Vs = \Delta H \cdot A$$

Then

$$W = \frac{\gamma w Vw}{\gamma s Vs} = \frac{\gamma w}{\gamma s} \frac{Vw}{\Delta H \cdot A - Vw}$$

Furthermore

$$\Delta H = \left(1 + \frac{\gamma w}{W \gamma s}\right) \frac{Vw}{A} \tag{30}$$

The balance of water quantities inside the settled volume is represented as follows:

$$\frac{d(Vw)}{dt} = (k_1 + E)A \tag{31}$$

Differentiating Equation 30, we have

$$\frac{d(\Delta H)}{dt} = \left(-\frac{\gamma w}{\gamma s}\frac{1}{w^2}\frac{dw}{dt}\right)\frac{Vw}{A} + \left(1 + \frac{\gamma w}{\gamma sw}\right)\frac{1}{A}\frac{d(Vw)}{dt}$$

$$\frac{\gamma w}{\gamma s}\frac{1}{w^2}\frac{Vw}{A} = \frac{1}{w^2}\frac{WVs}{AH} = \frac{1}{W}\frac{AH - Vw}{AH} = \frac{1 - n}{W}$$

$$\text{Porosity } n = \frac{Vw}{AH} = \frac{e}{1 + e} = \frac{\frac{\gamma s}{\gamma w}W}{1 + \frac{\gamma s}{\gamma w}W}$$

$$\frac{d}{dt}\left(\frac{\Delta H}{H}\right) = \left(1 + \frac{\gamma w}{\gamma sW}\right)\left(\frac{k_1 + E}{H}\right) - \frac{1}{W\left(1 + \frac{\gamma s}{\gamma w}W\right)}\frac{dw}{dt} \tag{32}$$

From this equation, we can calculate the value of k_1, because the values of $\frac{d}{dt}\left(\frac{\Delta H}{H}\right)$ and $\frac{dw}{dt}$ are measured. The change rates of $\frac{\Delta H}{H}$ are plotted in Figure 6.

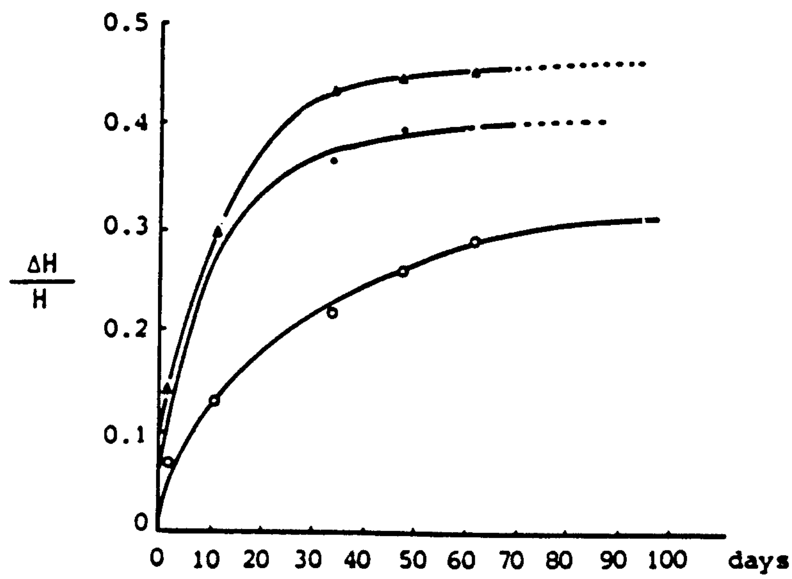


Figure 6. Variation of $\frac{\Delta H}{H}$.

As shown in Figure 7, the apparent permeability coefficient of the dredged material decreases rapidly with time.

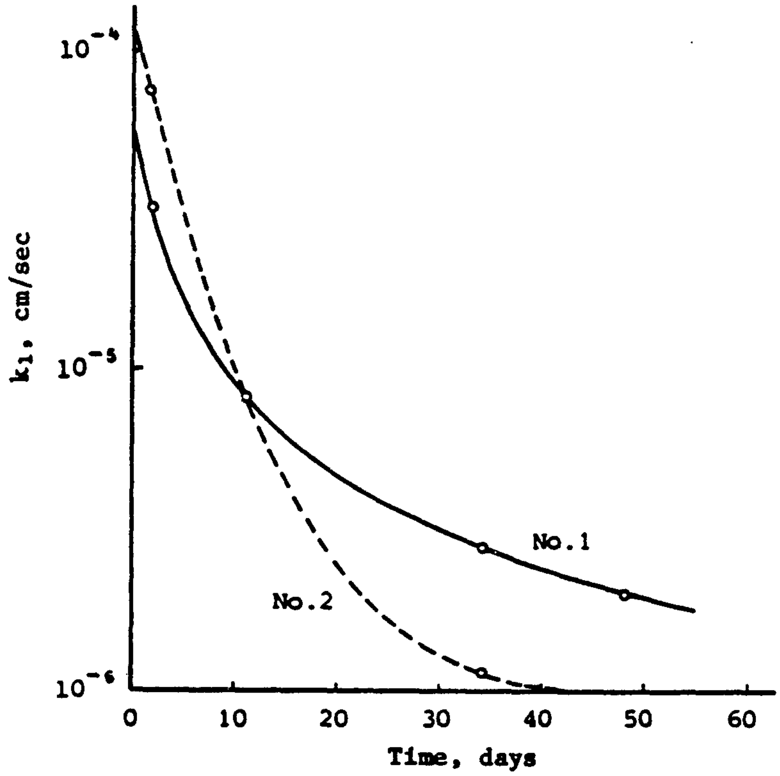


Figure 7. Variation curve of k_1

SHRINKAGE COEFFICIENT

Shrinkage coefficient is defined as follows:

$$\frac{\Delta H}{H} = \frac{\Delta W}{Cs}$$

From the linear relationships between $\frac{\Delta H}{H}$ and ΔW, the coefficient Cs is obtained. The relationships between them for our study are indicated in Figure 8.

As the figure shows, the curve is not always straight. In the early stage of dewatering it is nearly straight, but it is curved near the end of the test. Therefore, it appears reasonable to induce the curved relationships between water content change and shrinkage.

In this case, it seems that it is more practicable to use $\frac{\Delta W}{W}$ instead of ΔW.

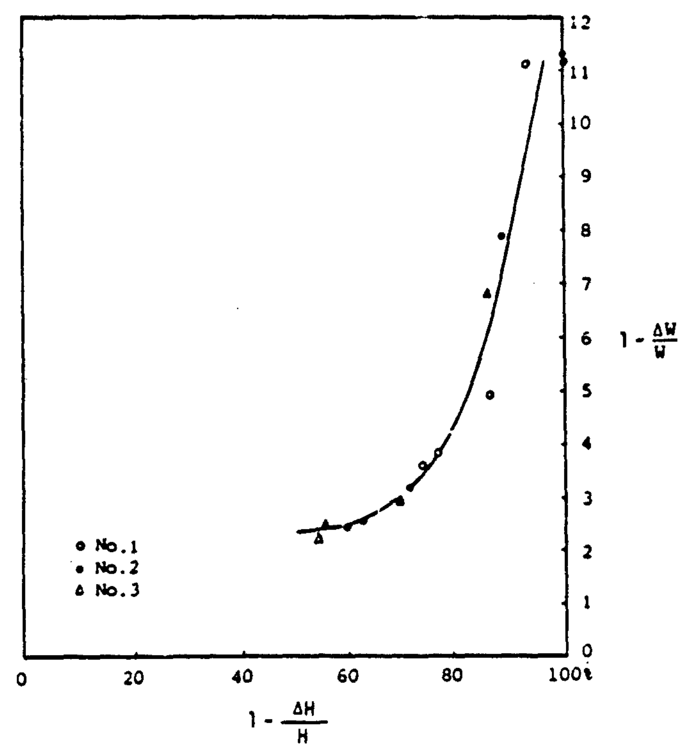


Figure 8. Relationships between $1 - \frac{\Delta H}{H}$ and $1 - \frac{\Delta W}{W}$

Figure 9 shows the relationships between the measured values of $1 - \frac{\Delta H}{H}$ and $1 - \frac{\Delta W}{W}$.

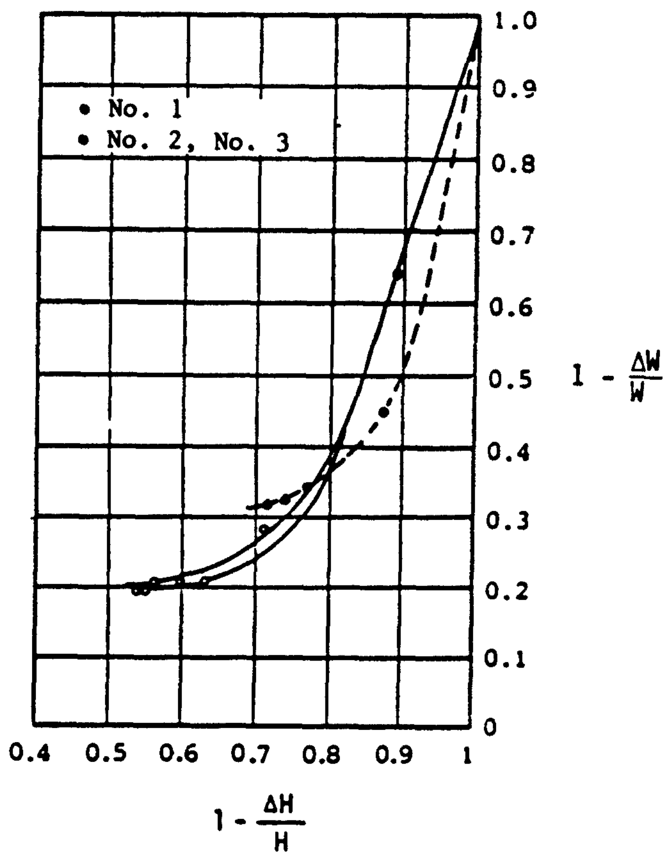
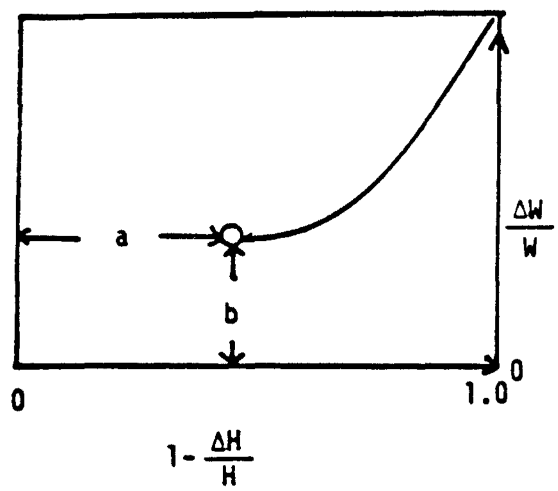


Figure 9. Relationships between $1 - \frac{\Delta H}{H}$ and $1 - \frac{\Delta W}{W}$

Considering the convergence of the curve, we assume the following parabolic relationship:

$$\left(\frac{1 - a - \frac{\Delta H}{H}}{1 - a}\right)^2 = \frac{\frac{\Delta W}{W} - b}{1 - b} \tag{33}$$



The coordinates of a and b denote the point of convergence. We obtain the following data for three ponds:

No. 1	a = 0.70	b = 0.31
No. 2	a = 0.60	b = 0.2
No. 3	a = 0.54	b = 0.19

DECANT POINT

Dredged material research in the United States suggested that the decant point, defined as the water content at which cracks begin to develop, is approximately 1.8 times the Atterberg liquid limit. The average water content of the ultimate crust was suggested to be approximately 1.2 times the Atterberg plastic limit. Our test results are examined from this point of view in the following paragraphs.

Figure 10 shows the state of pond No. 2 after 7 days, when it began to develop cracks at the surface. As the liquid limit of the tested dredged material is 240 percent, the water content (which is 1.8 times this) is 430 percent. As Figure 11 shows, the water content after 7 days is 400 percent. Therefore, we can say that the decant point corresponds to a value of about 1.7 times the liquid limit.

In Figure 11 it is seen that the water content converges to 240 percent. That is, the average water content of the dredged material at the end of 60 days is nearly equal to the liquid limit. As compared with this, the convergence point of pond No. 1 is 1.5 times the liquid limit (Figure 12).

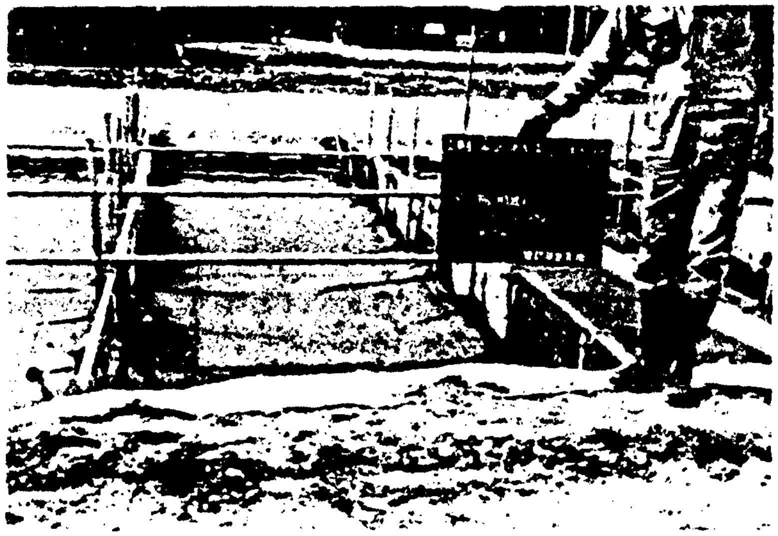


Figure 10. Desiccation after 7 days

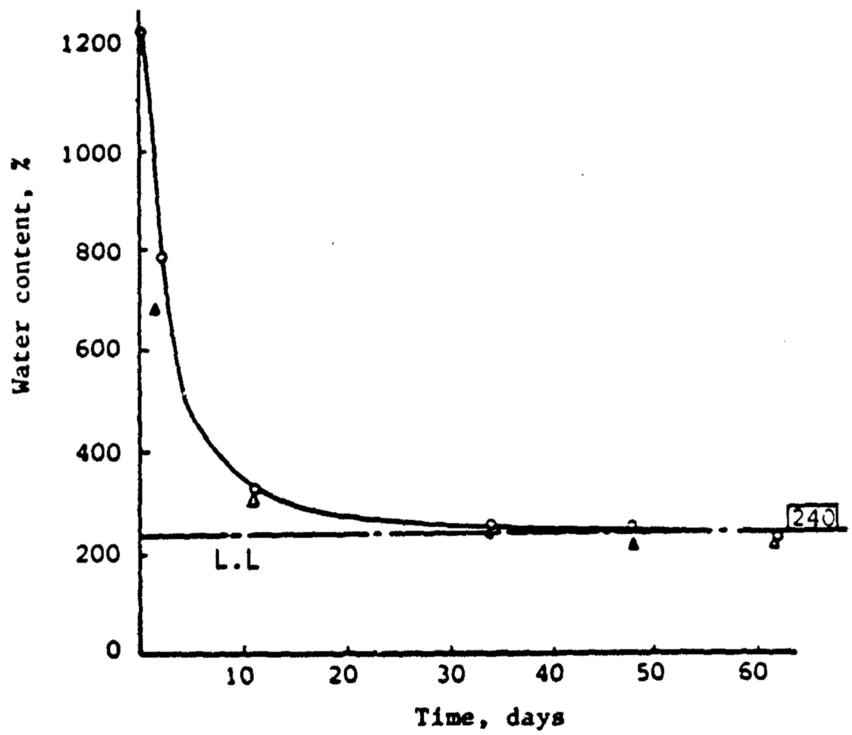


Figure 11. Convergence of water content of pond No. 2

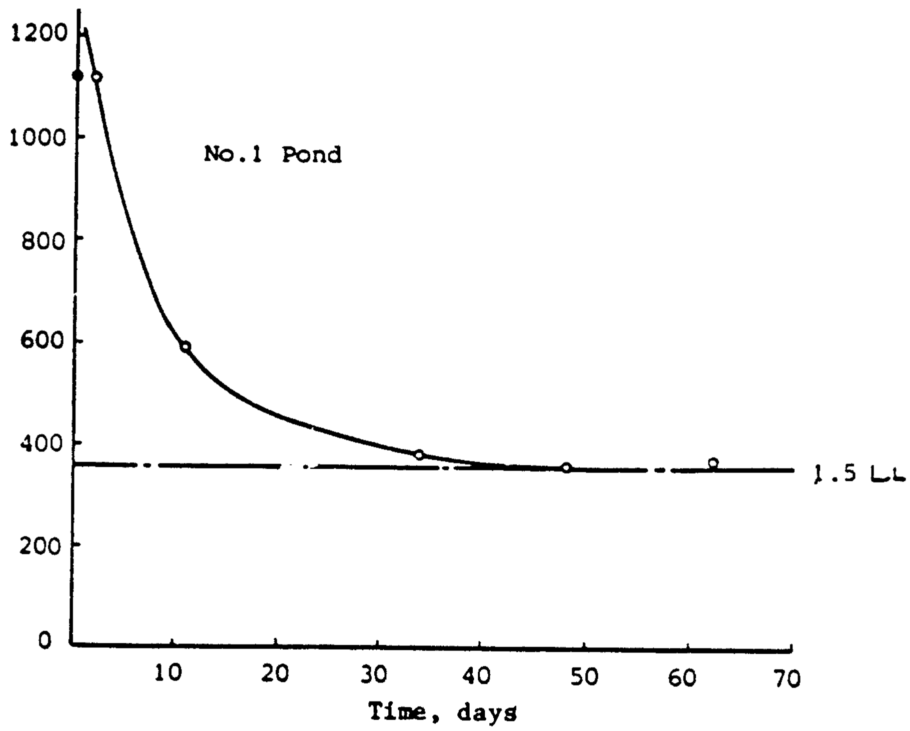


Figure 12. Convergence of water content in pond No. 1

CONCLUSIONS

In the management of dredged material, the most important matter is to dewater the material as quickly as possible. Given such a necessity, our test on bottom dewatering was conducted. Although dewatering by gravity drainage has been investigated from the earliest days, practical applications of our test seem rare.

It was found that dewatering of dredged material by gravity drainage is very effective in lowering the water content within a short time period. We have also learned much about the drainage behavior of dredged material from the soil mechanics point of view.

RAPID DEWATERING TEST OF DREDGED MATERIAL IN SITU

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ABSTRACT

The most popular method of reducing the volume of dredged material is natural evaporative dewatering. This method necessitates a long desiccation period of about 10 months and a large space. Conditions like these are difficult to overcome and the solution of water pollution problems, especially in lake restoration. To implement pollution control projects it is necessary to dewater dredged material as rapidly as possible and to overcome the unfavorable conditions mentioned above.

To meet these needs, a rapid dewatering test was conducted in Lake Suwa. This paper reports the test results.

OUTLINE OF TEST

The test was performed on the banks of Lake Suwa (Figure 1). The sediment, which was hydraulically dredged, was conveyed to the test ponds by a branch pipe (Figure 2). To determine the differences between sun-dried and bottom drainage ponds, three kinds of pond were constructed as shown in Figures 3 and 4.

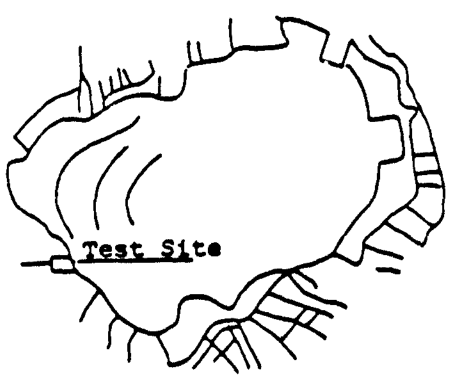

Figure 1. Test site

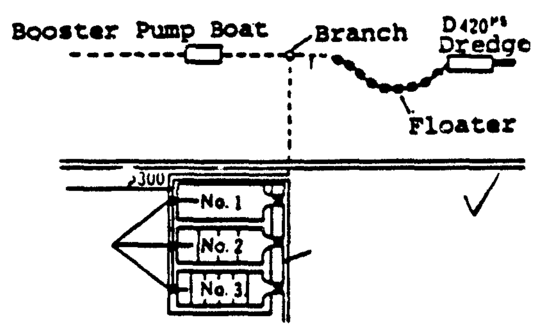

Figure 2. Conveying dredged material

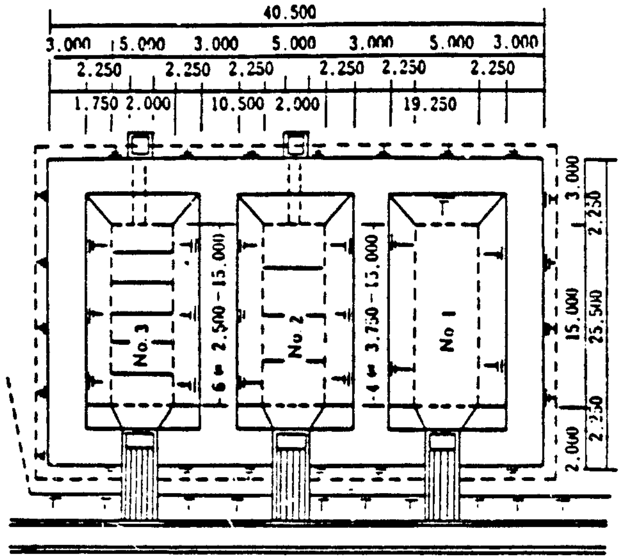

Figure 3. Plan view of test ponds (meters)

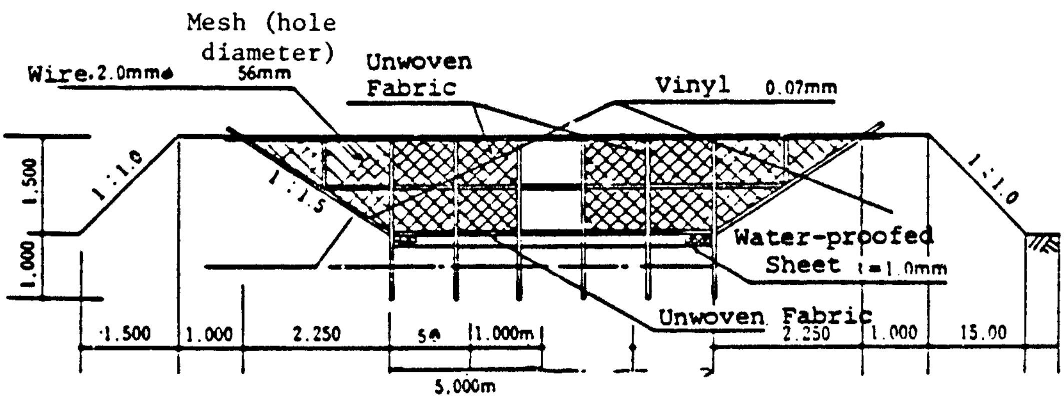

Figure 4. Elevation view of test ponds

Pond No. 1 was a conventional pond for sun drying, and Ponds No. 2 and No. 3 had a filtrating membrane (polypropylene) at bottom and vertically set membranes (polypropylene). Each pond had a surface area of 130 m^2, a bottom area of 75 m^2, a volume of 234 m^3, and a depth of 1.8 m.

The side walls of each pond were covered by vinyl sheets to prevent washouts. The bottoms of Ponds No. 2 and No. 3 were provided with waterproof sheets to prevent water permeating underground and possibly degrading underground water. Gravel stones were spread on the waterproof sheets to a thickness of 0.2 m to facilitate outflow of water (Figure 5).

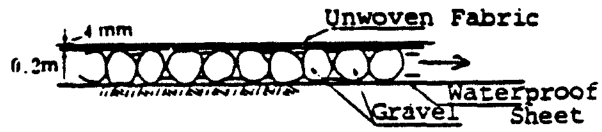

Figure 5. Gravel layer

The bottom filter sheet was made of a polypropylene unwoven fabric. The vertical membranes were of the same material, and served to promote the fall of water along their surfaces. Pond No. 2 had three vertical membranes and Pond No. 3 had five.

The layout of the test plant is indicated in Figure 6. The test material was conveyed by a branch pipe and poured into ponds. To increase the permeability coefficient of the dredged material, flocculants (PAC and polymer) were injected into the pipe at the point just before the pipe exit. Until the dredged material slurry reached the prescribed thickness (1.5 m), excess water was allowed to flow over the flashboard. The test began when the accumulated thickness of sediment became about 1.5 m. The drain valve was then opened and the drain water was pumped out through the reservoir pit. Quantities were measured at prescribed intervals.

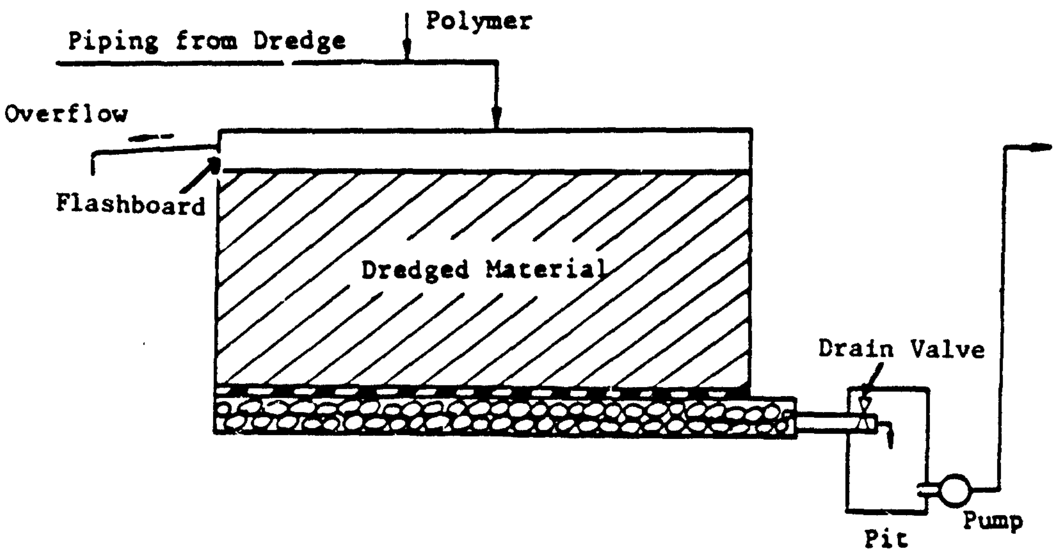

Figure 6. Layout of test plant

PROPERTY OF DREDGED MATERIAL TESTED

The property of the dredged material is shown in Table 1. A triangular diagram of the soil is shown in Figure 7.

TABLE 1. PROPERTY OF DREDGED MATERIAL

		Pond No. 1	Pond No. 2	Pond No 3
Grain Size	Gravel (>2000μm), %	0	0	0
	Sandy (74-200μm), %	1	1	1
	Silty (5-74μm), %	26	26	26
	Clayish (<5), %	73	73	71
	Max. size, mm	0.840	0.840	0.840
Consis-tency	Liquid limit, %	237.7	245.0	239.2
	Plastic limit, %	102.8	104.2	104.0
	Plastic index	134.8	140.8	135.2
Specific weight, g/ℓ		2,496	2,491	2,489
Water content, %		1,110	1,240	1,240
Unit weight, g/1000 cm^3		1,050	1,032	1,032
Shrinkage limit, %		80	72	80
Compression index		2.18	2.29	2.45

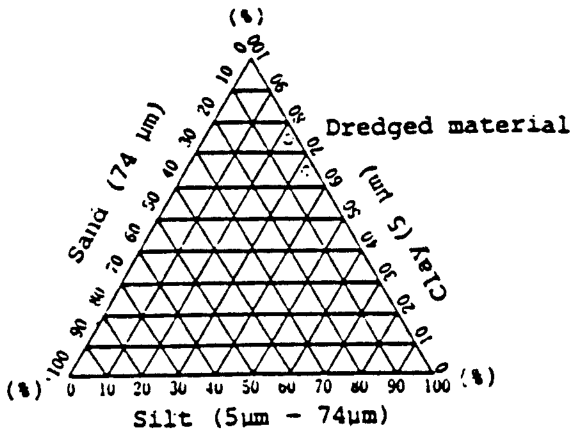

Figure 7. Triangular diagram of soil

As a clayish substance accounts for about 70 percent of the volume, the grain size of the tested dredged material is extremely small, and its liquid limit is very high, indicating about 240 percent. The test results for such a small material may not be applicable to other materials.

Since the soil condition is very unfavorable in this case, it is presumed that much better results would be obtained for larger grain sizes.

TEST RESULTS

Water Content

The variation in water content at the upper layers is shown in Figure 8. The water content decreases rapidly within 10 days, and after that very slowly. There is a big difference between Ponds No. 1 and No. 2.

For Ponds No. 2 and No. 3 we can say that dewatering is almost complete within 10 or 15 days.

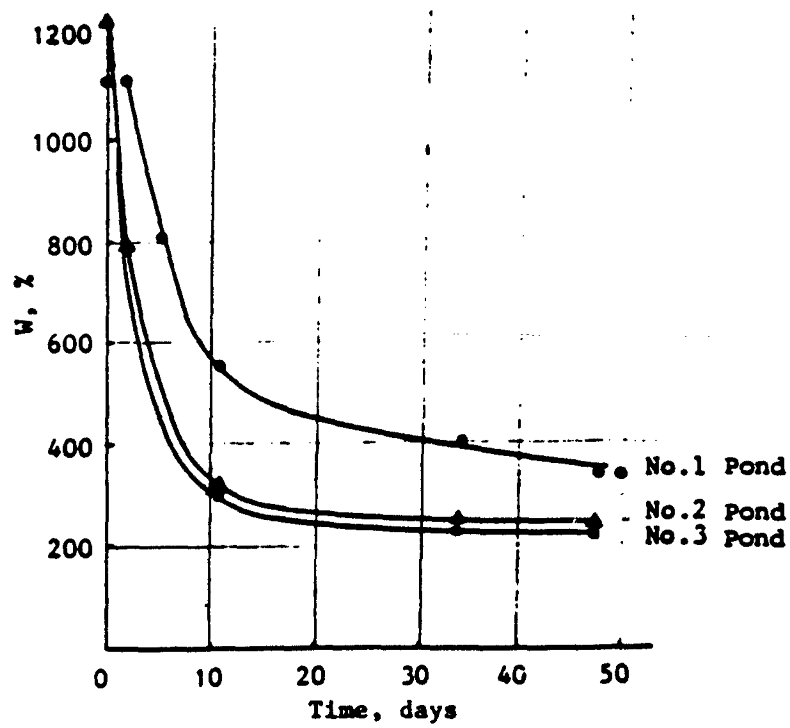

Figure 8. Variation of water content

Settlement

The change in settlements due to shrinkage is shown in Figure 9. The difference between sun-dried and bottom-drained ponds turned out to be more than just water content. We can also see a difference between Ponds No. 2 and No. 3. The pond with five vertical membranes displayed larger settlements than the pond with three membranes. In Pond No. 3, the settlement was almost complete in 30 days.

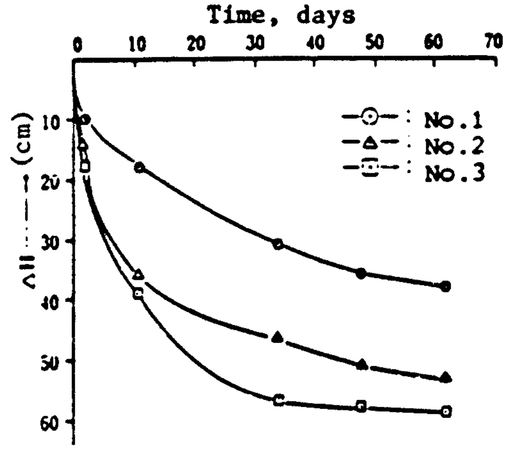

Figure 9. Variation of settlement

Drainage Water Quantities

Water quantities which flow out from the bottom change with time as shown in Figure 10. This figure shows that most of the water contained in dredged material has drained in about 10 days.

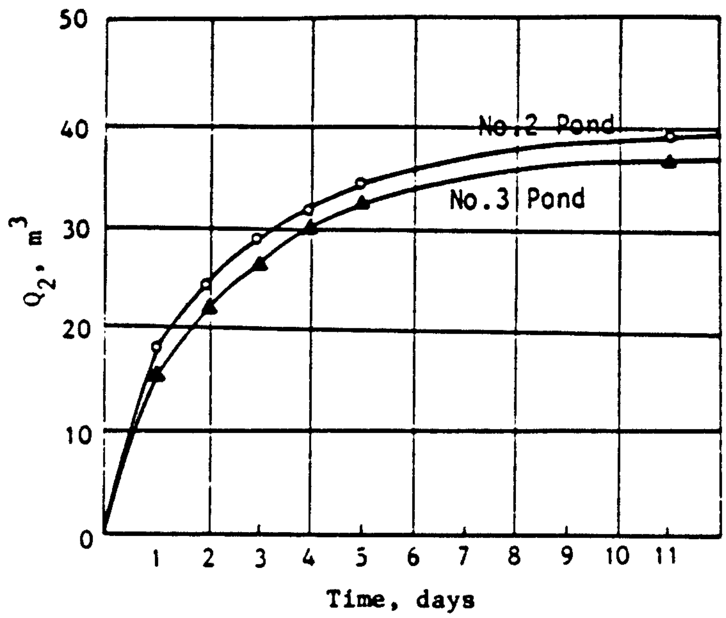

Figure 10. Variation of drainage water

Desiccation Cracks

With the advancement of drainage, desiccation cracks begin to develop. As the liquid limit of the test material is about 240 percent, the corresponding decant point (1.8 times) becomes 432 percent. This point comes

after 7 days in Ponds No. 2 and No. 3 (Figure 11). It has been observed that surface cracks begin to develop at this time.

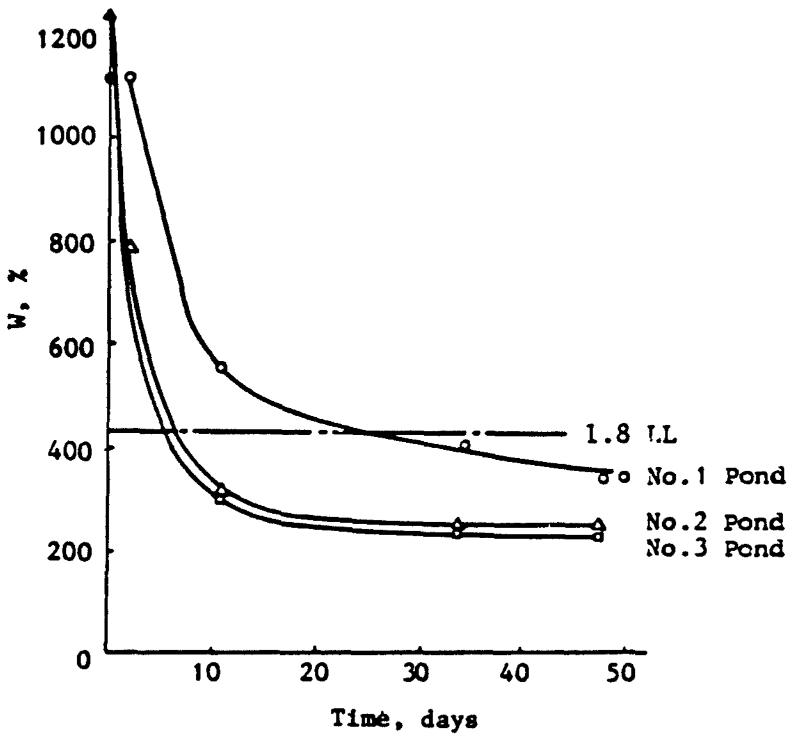

Figure 11. Decant point

There was a large difference between sun-dried and bottom-drained ponds. Figure 12 shows crack development in Pond No. 2 after 13 days, and Figure 13 shows crack development in Pond No. 1 after 27 days. In Pond 2 well-developed cracks are observed while Pond No. 1 has no cracks. After about 10 days, the surface of Pond No. 2 was hard enough to stand on. However, even after 2 months, one could not stand on Pond No. 1.

Soil Property After 2 Months

The compressive strength qu of the desiccated polygon after 62 days is shown in Table 2.

The consolidation test results of the polygon are indicated in Table 3. As shown in these tables, the desiccated dredged material can easily be handled by clamshells and transported by dump trucks.

Vertical Distribution of Water Content

The vertical distribution of water content in Pond No. 2 is shown in Figure 14. The curve after 11 days is nearly straight, but the curves after 34 and 48 days are completely straight.

Such results arise necessarily from the fact that desiccation cracks reach to the bottom at some time interval after 11 days but before 34 days.

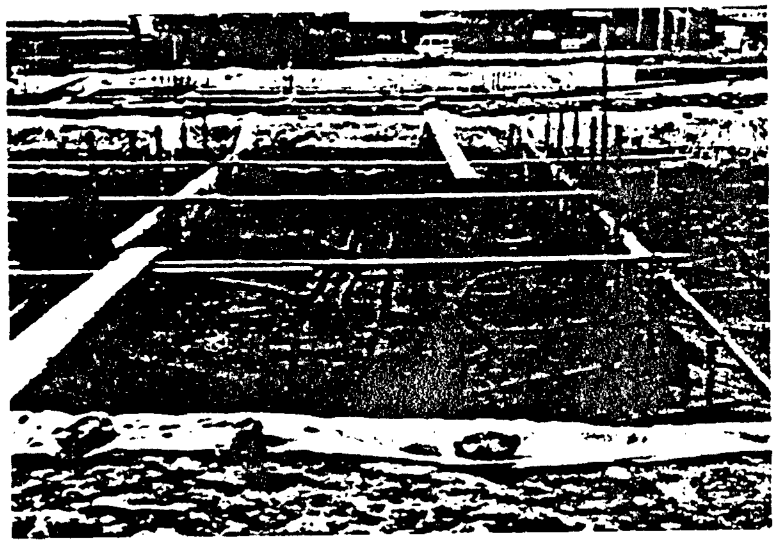

Figure 12. Crack development after 13 day
(W ≑ 300%) in Pond No. 2

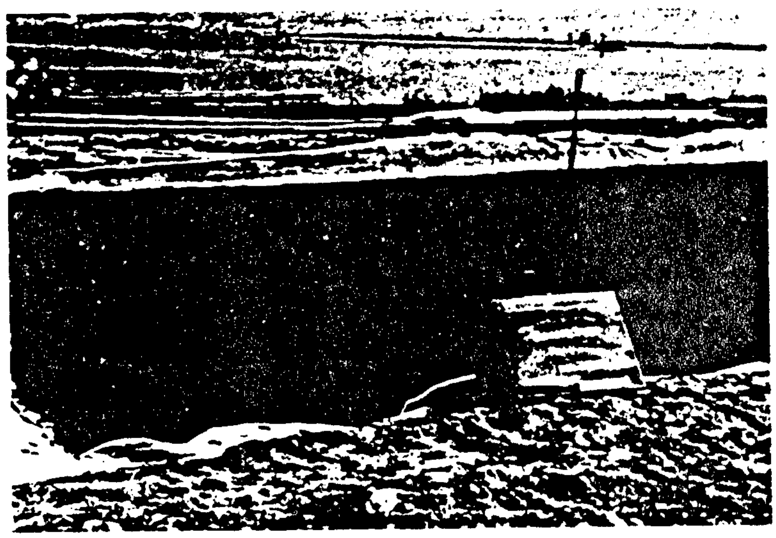

Figure 13. Appearance after 27 days in Pond No. 1
(W ≑ 450%)

TABLE 2. COMPRESSIVE STRENGTH OF DESICCATED POLYGON

Pond	Point	Layer*	Depth cm	qu kg/cm^2	W %
	A	U	--	--	343
No. 1		L			339
	B	U	--	--	403
		L			340
	A	U	24	0.162	221
No. 2		L	48	0.106	256
	B	U	24	0.160	239
		L	48	0.148	263
	A	U	24	0.179	219
No. 3		L	48	0.116	251
	B	U	24	0.174	233
		L	48	0.168	243

* U = Upper layers, L = lower layers.

TABLE 3. CONSOLIDATION TEST RESULTS

	Pond No. 1	Pond No. 2	Pond No. 3
Yielding point, kg/cm^2	0.16	0.163	0.214
Compression index	1.66	1.70	2.20
Coeff. of consolidation, cm^2/min	1.70×10^{-1} ~ 7.02×10^{-1}	1.63×10^{-1} ~ 6.58×10^{-1}	1.92×10^{-1} ~ 5.63×10^{-1}
Coeff. of volume compressibility, cm^2/kg	9.82×10^{-2} ~ 5.03×10^{-1}	9.36×10^{-2} ~ 5.43×10^{-1}	9.18×10^{-2} ~ 5.94×10^{-1}

In comparison, the curves in Pond No. 1 are not straight, indicating high contents in upper layers and low contents in lower layers (Figure 15).

The reason the water contents in the lower layers are unexpectedly low lies in the fact that some quantities of drained water have permeated underground.

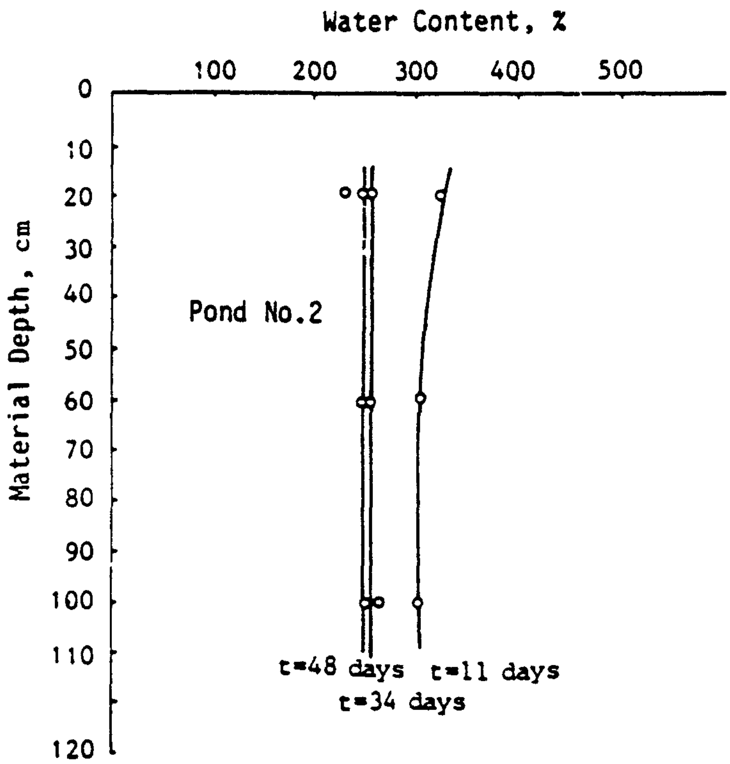

Figure 14. Vertical distribution of water content in Pond No. 2

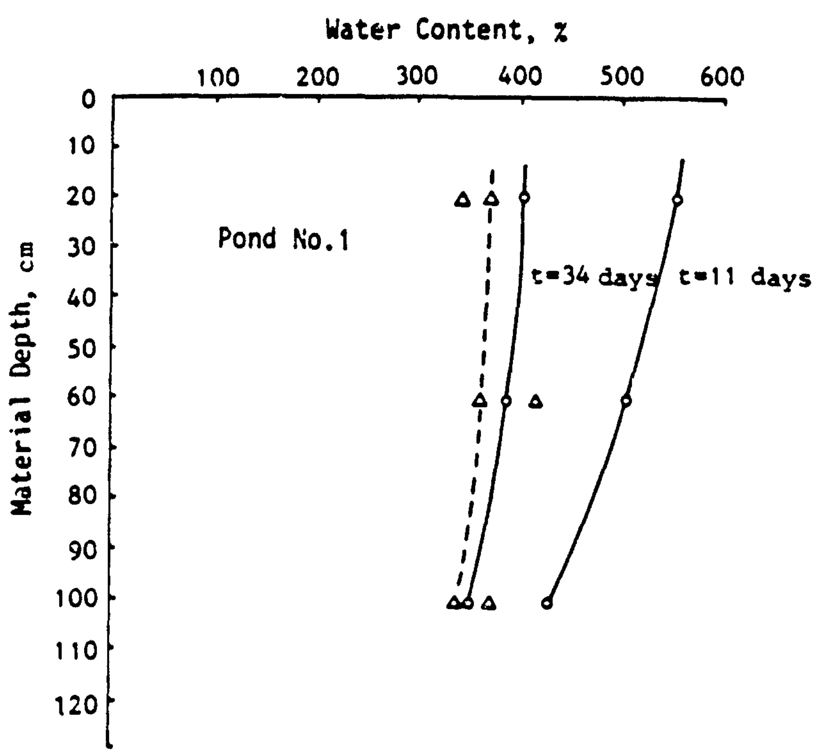

Figure 15. Vertical distribution of water content in Pond No. 1

Water Quality of Drainage

The quality of water which is exhausted from the bottom is shown in Table 4. At the beginning of dewatering, the drainage water had some suspended solids, but after 24 hr it became very clean.

TABLE 4. WATER QUALITY OF DRAINAGE

Hour	Pond No. 2 Concentration of SS, mg/ℓ	Pond No. 3 Concentration of SS, mg/ℓ
0	100	28
1	24	14
6	20	8
24	4	3
30	3	2
48	2	2

CONCLUSIONS

As mentioned before, we have obtained unexpectedly good results in our tests. The concept that water in dredged material should be drawn out by gravity was verified by the test.

In our country, there are many cases in which dredged material must be placed in ponds temporarily and after dewatering transported to final disposal sites. For such cases, the bottom drainage method is very effective because large quantities of dredged material can be treated in small ponds.

Although the basic points regarding this method were explained, there remain several points which should be improved for practical application.

MECHANICAL DEWATERING OF DREDGED SLURRIES

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ABSTRACT

Over the last 5 years, significant developments have occurred in dewatering; belt press technology, computer finite element modeling for structural design, improved high molecular weight preconditioning chemicals, and advanced belt weave and strength characteristics have all been key factors.

A 2.5-m-wide heavy duty belt press can dewater high density sludge at a rate of 20 to 30 tons/hr (dry basis). The unit is the largest factory preassembled module, and thus is transportable from site to site. It can be mounted on a concrete slab, truck mounted, or mounted on a barge to eliminate dredge-to-shore pumping and piping problems. Energy required for dewatering is equal or less than current energy levels expedient when pumping from dredge to shore. We anticipate that an 83 percent volume reduction would occur when converting a 15 percent solids dredged slurry to a 70 percent solids cake.

Near term, belt press dewatering may especially fit into dredging operations where confinement is necessary <u>or</u> where chemical contamination is present in the dredgings and total solids capture is necessary. Final cake may be placed directly into berm or dike construction, or, where chemical contaminants build up significantly, chemical fixation is feasible.

INTRODUCTION

Numerous dredging techniques are in use today, many of which are site specific (1). Our approach over the years has been directed to the field site as well. Therefore, the programs described herein cover an "enviroenergy" spectrum and touch on subjects from bench scale work up to large volume, continuous processing. Application of this technology must be tailored to the site to provide the most expedient and cost-effective solution.

BACKGROUND

Through the early 70's, vacuum filtration was the dominant process for sludge dewatering. Centrifugation was emerging as a preferred process in some applications. Also, the batch-continuous filter press was making first appearances in the municipal sludge dewatering field in the United States. This field has always been confronted with conservatism, some justified because of the wide variation in sludges and some just typical of operation and maintenance. When by the mid 70's the energy crisis took its full toll, "traditional thinking" was overshadowed by the thought that we could no longer direct 40 percent of the plant energy to sludge dewatering and management. Thus, during the mid 70's the filter belt press emerged because it required only one fifth the energy of the vacuum filter. Further concern over available landfill and agricultural spreading created an incentive for volume reduction, and organic polymers rapidly replaced the voluminous chemical conditioners lime, ferric chloride, and alum. Finally, new, high-rate batch continuous filter presses held the promise of dewatered cake solids levels suitable for incineration without addition of auxiliary fuel.

Any review of available literature on dredging technology reveals that the concept of applying "state of the art" mechanical dewatering is not new (2). In the mid 70's there were advocates of mounting vacuum filters on barges while others claimed economics were prohibitive. Concurrently, some concern developed over migration of toxic or hazardous chemicals, possibly associated with the finer portions of the particulates, conceivably lost in the filtrate. Thus, it seems that the subject of mechanical dewatering for dredging has not been pursued aggressively for several years.

During this time, belt press technology progressed rapidly in mechanical design; for example, now there are reliable tracking systems and structural design of rolls and main frame by computer (finite element) modeling (3). Belt strength and weave technology have improved rapidly, achieving longer life; a broad selection is now available for filtration variability. Also, through use of polymer chemistry--high molecular weight cationics are constantly improving. For example, earlier dredging dewatering investigations (4) concluded that original polymers were ineffective for high concentration slurries (10-20 percent) because the polymer could not be completely dispersed to all the fines; thus, fines not treated chemically were not captured. Now, polymer is routinely injected 10 to 20 pipe diameters upstream of the distribution head box when handling feed slurries concentrations as high as 40 percent solids.

Our own experience confirmed rejection of the mechanical dewatering of dredgings via vacuum filtration. When we first replaced filters with belt presses in a major plant in Wisconsin, the existing vacuum filters were capturing only 50 percent of the solids; the fines were sent back to the head end of the plant. This inventory of solids buildup had the entire biological plant process in extreme jeopardy. Our prototype belt press demonstrated 98 to 99 percent solids capture; within 6 months the filters were completely abandoned in favor of belt presses. The refractory solids inventory was eliminated and the biological process efficiency restored. Once the "fines inventory" dropped out of the system, the plant found it relatively easy to

dewater sludge, and chemical costs dropped off. These presses have been performing continuously for 3 years (5).

CURRENT DEWATERING PROGRAM

While our early efforts were directed toward lighter organic, biological sludges, it was evident from work for Rexnord's Gundlach Coal Division that the belt press was solving the problem of coal tailings and pipeline slurry (6) dewatering. It also occurred to us that the earlier organic press efficiencies could impact clean coal dewatering where vacuum disk filters were being used. The capital cost of commercial sewage sludge belt press units was being paid off in 2 years in savings from existing vacuum filters operation and maintenance costs. Thus, we rapidly accumulated bench field data at a number of eastern U. S. coal sites, and from two available coal pipeline slurry sites. A tabular summary of coal characteristics is included in Table 1 and, as expected, a wide variability in clay, pyrite, and coal content and particle-size distribution exists. Using the two-phase bench testing process shown in Figures 1 and 2, the following selections were made:

a. Optimum polymer selection and dosage.

b. Feeds solids residence time for removal of free drain and pressure water.

c. Solids capture rate of upper deck and lower pressure roll water.

d. Cake solids concentration.

e. Cloth media selection to ensure proper cake release.

f. Alternative treatment strategies for capture of filtrate solids where water recovery and/or total solids confinement are necessary. (Clarified or filtered filtrate water can be reclaimed for belt wash water).

For dredging bench work where contaminants are present, concentrations can be measured in the amount reporting to the cake phase versus the filtrate phase. Also, cake volumes can be scaled up and matched to available storage areas. This avoids some uncertainty in predicting the rate of slurry compaction and volume required for long time storage service life for conventional impondment.

These test runs are developed from five 50-gal sample sizes and, armed with rule of thumb scale-up, belt press economics are defined and compared to alternative solids handling strategies. Considering feed sample variation, test results are completed in a week or less. Figure 3 illustrates typical coal tailings feed, filtrates, and cake.

With the field test feasibility program completed, the major design and application criteria were known and we could design and fabricate the full-scale unit. Figure 4 illustrates the basic size module, a 2.5-m-wide unit, the largest fully factory assembled, transportable unit possible. Figure 5 illustrates a separate upper expanded drain deck, frequently needed because

TABLE 1. SUMMARY OF CLASSIFYING COAL AND BELT PRESS DATA ON COAL TAILINGS, SCREENINGS, AND FLOAT

Date	Site	Location	Type Coal	Percent Total Solids	Percent Ash	Specific Gravity	Btu/lb	Finer Than 100 Mesh percent	Finer Than 200 Mesh percent	Effective Size mm	Uniformity Coefficient	pH	Alkalinity mg/l $CaCO_3$	Sulfur (percent of dry)	Total Dissolved Solids mg/l	Volume of Filtrate Removed in Gravity Drain percent	Polymer Dose $/ton	Cake Solids percent total solids	Filtrate mg/l	Percent Recovery	Percent Moisture in Cake
1-9-81	Consolid. Coal Co.	Pitts. Pa	Tailings	48	25	1.18	11,500	45	30	0.015	15.1	8.1	9,700	2.05	1300	16	0.38	79	1,880	99	21
1-12-81	Pyro Mining	Sturgis, Ky.	Tailings	19	38	1.07	7,450	45	27	0.022	11.0	7.4	2,600	3.21	3700	70	0.60	76	3,950	98	24
1-14-81	Old Ben #21	Ill.	Tailings	25	31	1.08	9,450	62	44	0.010	11.5	7.2	4,400	1.11	2800	32	0.98	69*	630	99	31
1-14-81	John Ross	Ill.	Tailings	21	29	1.04	9,950	60	39	0.013	9.6	7.4	3,930	2.23	2300	40	0.59	70	3,100	98	30
1-15-81	Freeman	Ill.	Tailings	38	31	1.16	8,580	26	16	0.045	9.3	7.2	10,660	2.31	5900	15	0.68	73	1,950	99	27
1-16-81	Inland	Ill.	Tailings	11	72	1.05	3,550	43	27	0.017	13.5	7.2	1,210	2.54	6000	67	0.72	76	11,560	90	24
1-20-81	Pyro	Ky.	Screening Cyclone	15	34	1.04	9,800	54	36	0.014	14.1	7.4	2,930	2.74	2100	65	1.32	72	820	[illegible]	28
1-29-81	Gibraltor	Ky.	Screening Cyclone	15	49	1.06	6,590	58	43	0.009	18.3	5.2	199	2.57	3200	46	2.11	69	4,300	97	31
1-29-81	Island Creek	Ky.	Screening Cyclone	14	34	1.04	9,200	57	37	0.017	9.7	7.3	2,590	2.92	5000	71	0.86	71	7,130	95	29
3-17-81	Jim Walters	Brookwood, Ala.	Tailings	20	63	1.07	4,580	45	29	0.014	16.4	8.1	6,200	0.76	1840	66	0.16	82	2,020	99	18
3-18-81	Republic Steel	Berry, Ala.	Tailings	33	51	1.01	6,680	68	48	0.011	10.6	8.0	700	1.34	570	19	0.18	77	6,250	98	23
1-14-81	John Ross	Ill.	Float	17	9	1.04	13,000	77	58	0.015	4.4	8.0	900	1.49	2500	23	0.92	63	2,040	99	37
1-15-81	Freeman	Ill.	Float	28	8	1.08	13,260	42	26	0.019	11.1	6.8	1,300	1.52	6100	18	0.58	70	1,430	99	30
3-17-81	Jim Walters	Brookwood, Ala.	Float	40	9	1.02	14,280	43	26	0.021	11.2	7.9	850	1.34	1790	36	0.05	80	4,300	99	20

* Density of cake = 82 lb/ft^3.

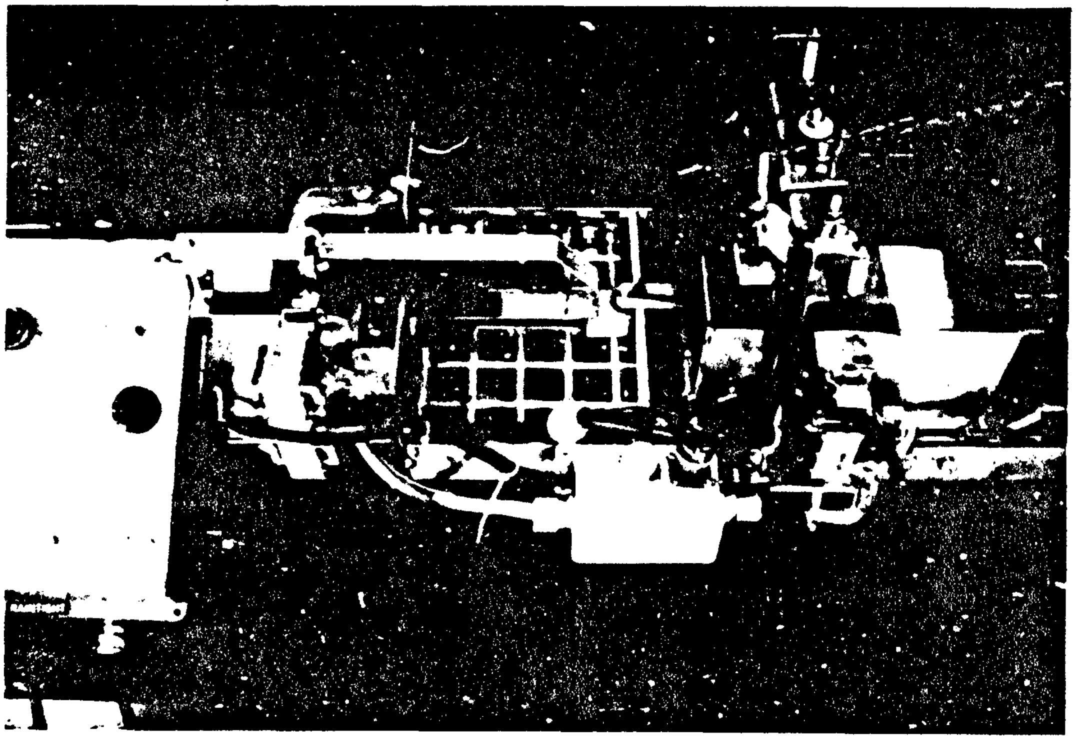

Figure 1. Bench test setup, Phase I

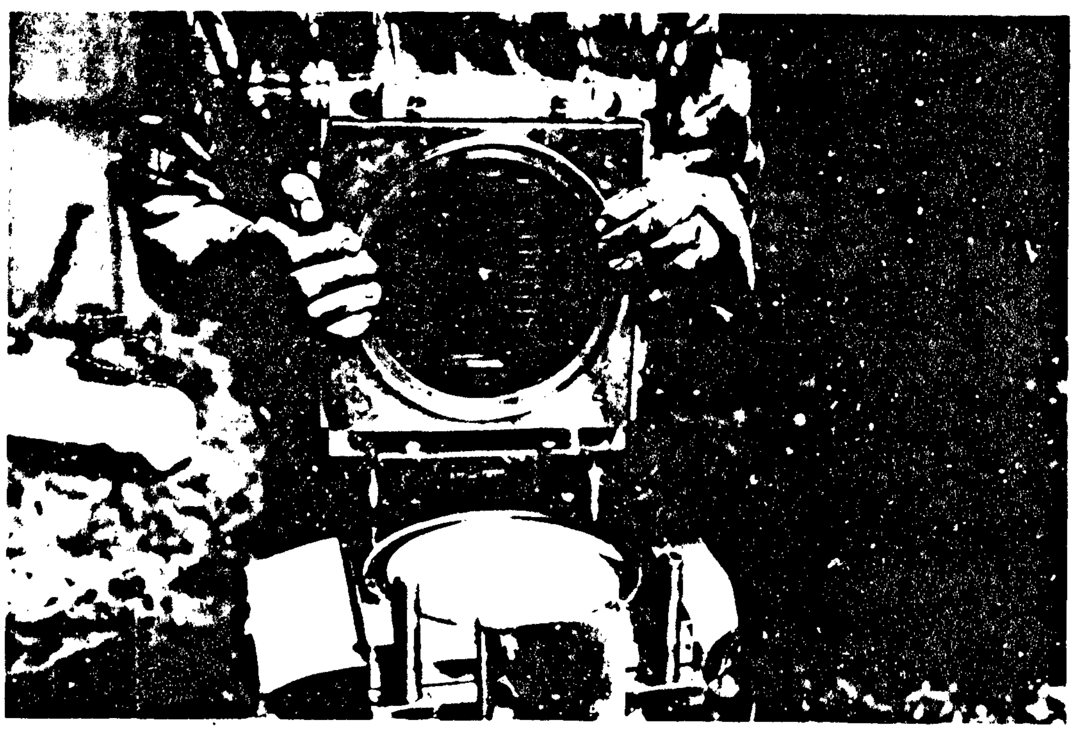

Figure 2. Bench test setup, Phase II

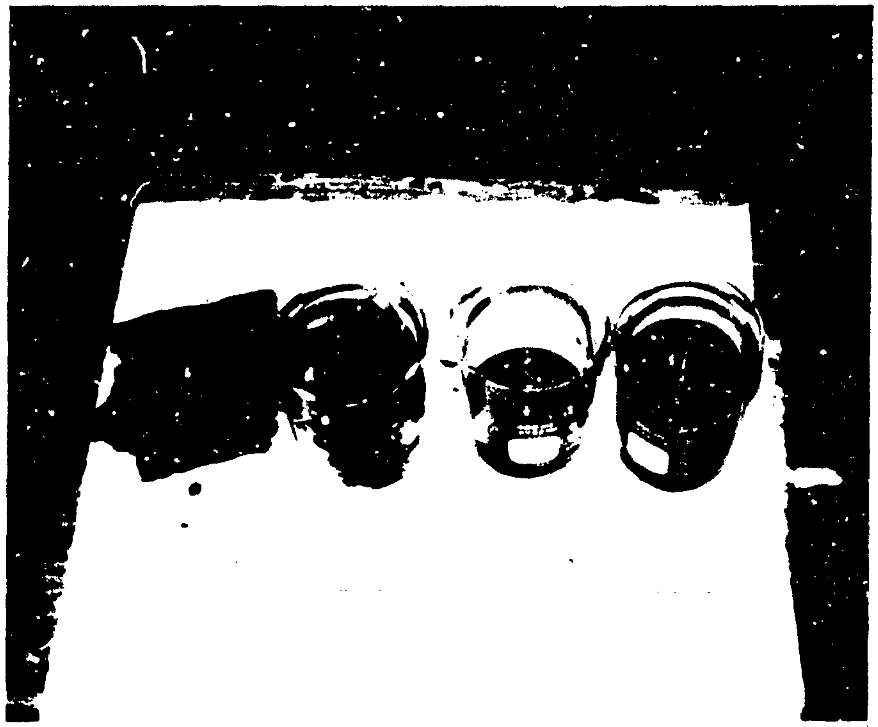

Figure 3. Typical bench test samples of coal tailings--feed, filtrates, and cake

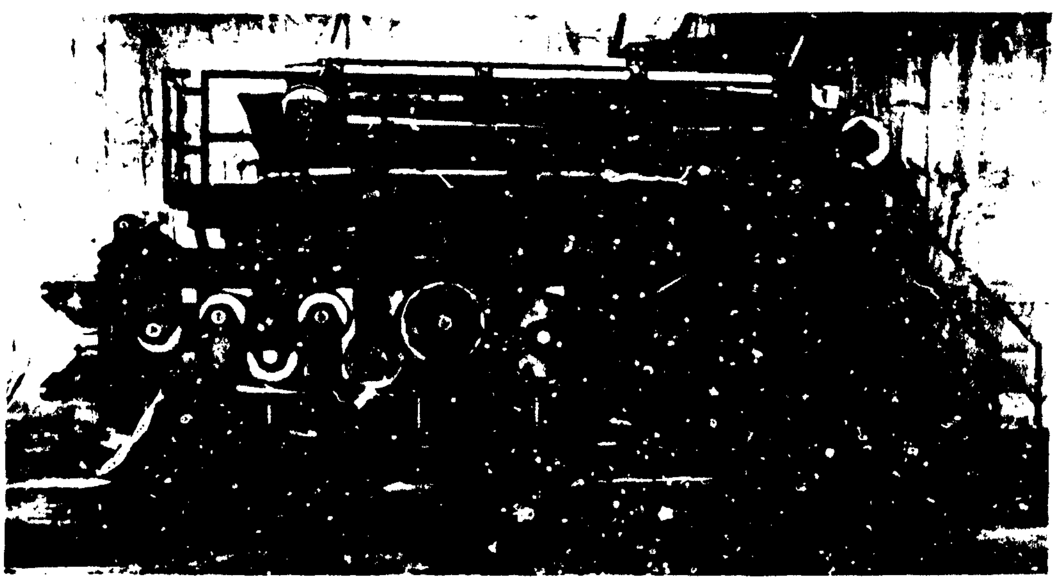

Figure 4. Factory-assembled 2.5-m-wide belt press

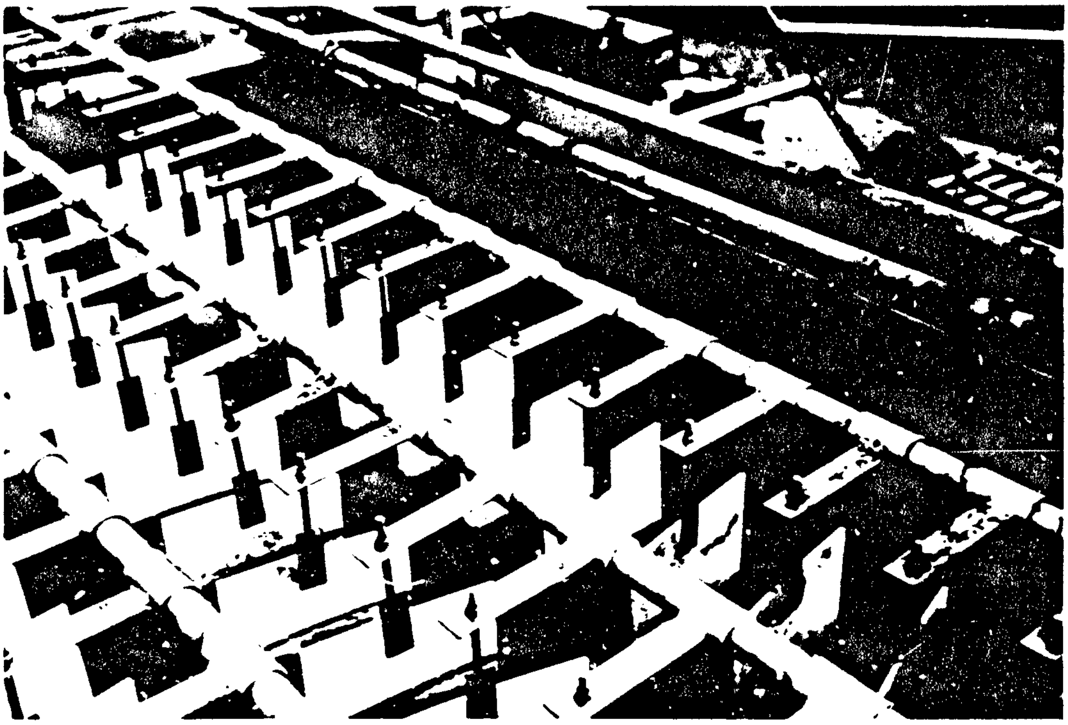

Figure 5. Upper expanded drain deck

the incoming slurry may be dilute in the 8 to 15 percent solids range where hydraulic loading governs. The upper deck also serves as a buffer or cushion to even out some feed variability before the slurry enters into the pressure section. When water is extracted on the upper deck, better solids "entrapment" occurs; hence, a higher overall solid capture is achieved versus pressing out loosely bound water. The high rate of water extraction permits the lower deck and pressure rolls to perform at higher solids loading rates, in some cases over 30 tons/hr (dry basis). Dewatering proceeds and a "barely pumpable slurry" is formed in the wedge section. (In dredging one may elect to stop the process at this point and still pump the solids from the barge or shoreline confinement, or proceed into the pressure rolls and produce a dry haulable cake, suitable for landfill compaction with standard earth-moving equipment). Dry cake is the objective in dewatering coal tailings refuse; i.e., the raw refuse at 10 percent solids, thickened if necessary to 30 percent solids, is concentrated on the upper deck to 50 percent solids with final cake formation through the press at 70 percent solids average, or 75 percent solids maximum.

In June 1983 the prototype was prepared for field testing and shipped to a coal mining and cleaning plant in the eastern Kentucky field. Figures 6 and 7 illustrate shipment, arrival, and installation of the unit. With factory assembly and modular shipment, the unit can be operational within days and readily moved from site to site. Figures 8-10 illustrate dewatering of coal tailings at the 30-tons/hr (dry solids basis) rate. Tests on sustained production are under way at this time.

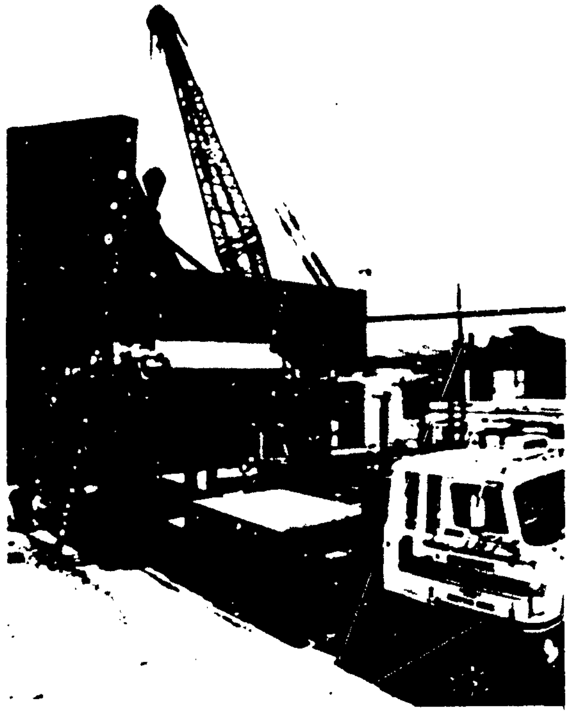

Figure 6. Shipment of 30-ton belt press

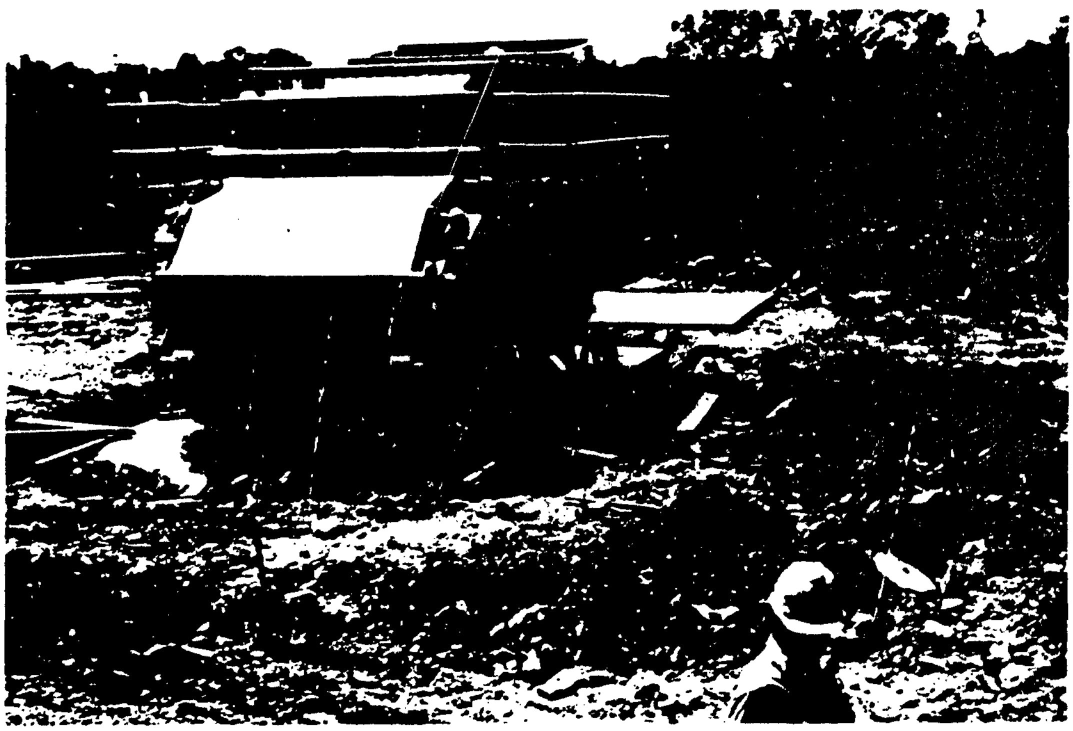

Figure 7. Field installation of press for coal tailings dewatering

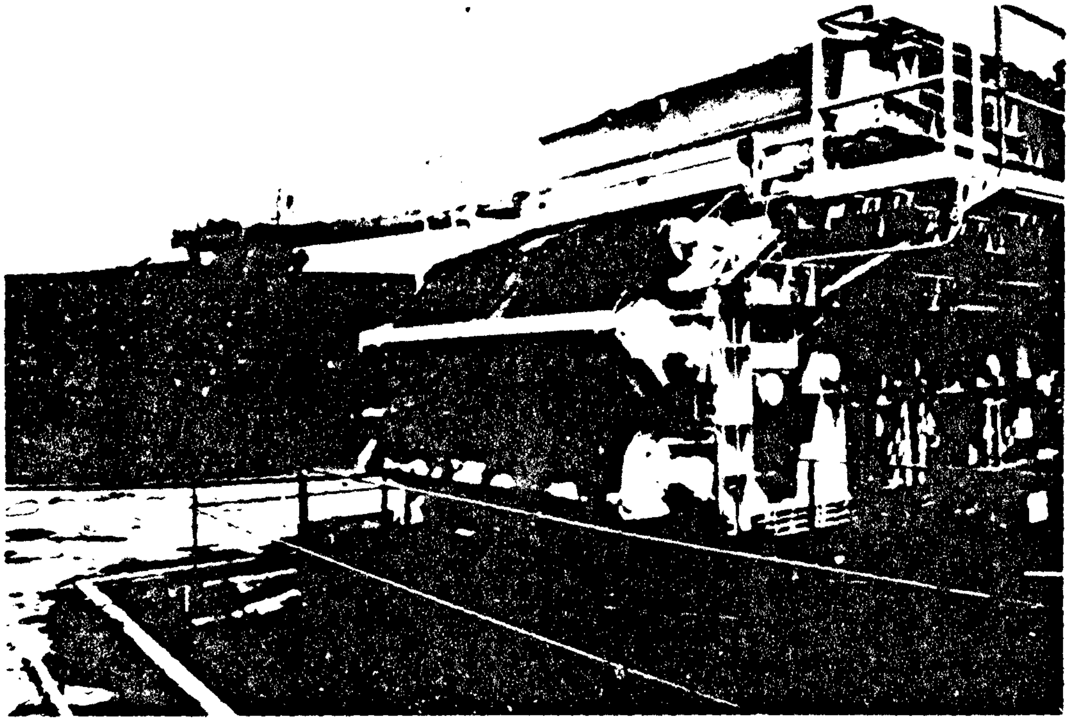

Figure 8. Dewatering of tailings at 20 to 30 tons/hr

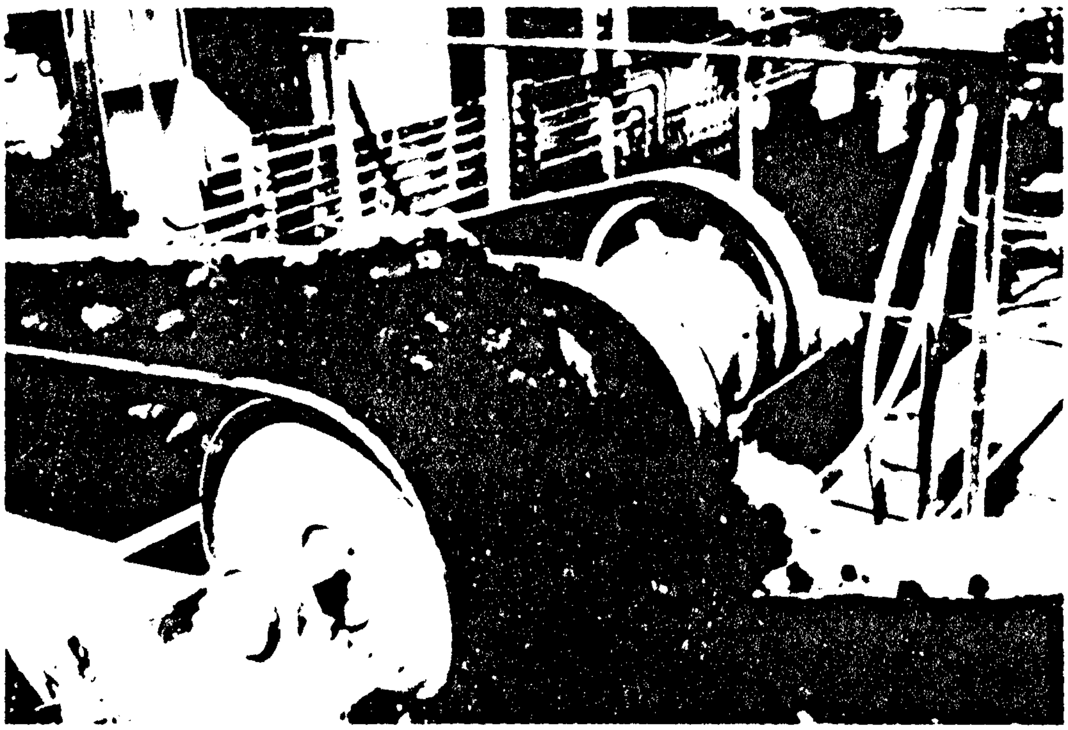

Figure 9. Closeup of coal tailings cake at 70 percent solids content

Figure 10. Tailings cake discharge and loading bunkers

WHY DEWATER DREDGE SLURRIES?

Economic justification of dewatering concerns:

a. Volume reduction versus handling, piping, hauling bulk liquid, or lagooning.

b. Moisture extraction. Any thermal process will be energy intensive if water is not extracted.

For dredging, volume reduction is the obvious potential justification. Using available coal tailings dewatering data, as it is reasonably comparable to some dredging characteristics, Figure 11 demonstrates specific volume reduction economics.

For example, a raw feed of coal tailings or pumped dredged material at 15 percent solids would represent a volume of 180 cu ft (5.1 cu m). Upper drain deck dewatering would achieve a solids concentration of 50 percent solids with a volume of 48 cu ft (1.4 cu m). Finally, roll press section dewatering would develop a stabilized cake solids concentration of 70 percent, and a final volume of 31 cu ft (0.9 cu m).

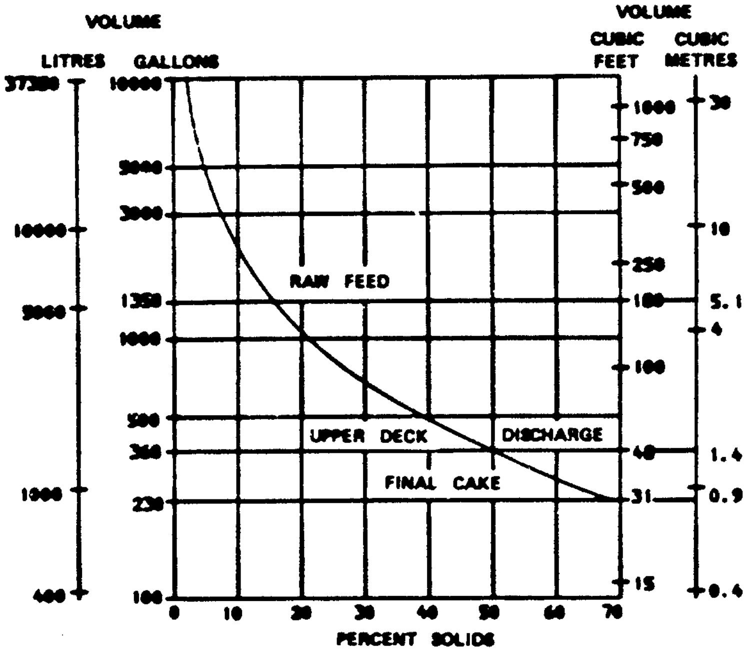

Figure 11. Slurry dewatering, slurry volume versus percent solids

Thus, volume reduction is as follows:

$$\frac{180-48}{180} = \frac{132}{180} = 73 \text{ percent through free drain deck} \tag{1}$$

$$\frac{48-31}{48} = \frac{17}{48} = 35 \text{ percent press section dewatering} \tag{2}$$

$$\frac{180-31}{180} = \frac{149}{180} = 83 \text{ percent overall volume reduction} \tag{3}$$

Because the greatest volume reduction occurs in the free drain section, one might question the economics of complete cake formation. First, the polymer chemical preconditioning costs will be the same with or without the roll press section, at 50¢ to $1.00/ton (dry solids basis). Second, the ultimate dredge solids fill location probably requires spreading and compaction or use as berm or dike material; hence, a drier cake for handling and hauling is necessary. Third, the drier cake will resist reliquification from rainfall; thus, erosion or leachate migration will be minimum. Revegetation is more likely to occur in one growth season or sooner.

Further investigation is necessary to establish where the on-barge dewatering and 83 percent volume reduction is cost-effective versus current practices of pumping or barging the slurry to shore, developing extensive impoundments, and accounting for proper environmental assimilation of the effluent, or significantly extending available dredge fill area capacity. The application in which the barge-mounted belt press concept may be near term is

in the area of total confinement of dredging containing toxic and hazardous materials.

Currently, dredging operations maintain 25,000 miles of U. S. channels and 1,000 harbors (7). This develops 250 to 300 million cubic yards of dredged material that must be properly reincorporated into the environment annually. Further it is estimated that 20 percent of the dredged material contains chemicals of concern and special confinement measures should be incorporated. Thus, 50 to 60 million cubic yards, say 55 million cubic yards, if dewatered and confined using a belt press system, would reduce the volumes to 9.5 million cubic yards.

Assuming 250 days/year operation, the 55 million cubic yards translates to 44.5 million gallons per day. Based on a 2.5-m unit capacity of 400 gpm and 1000-minutes/day operation and 20 to 30 tons/hr (dry solids basis), approximately 100 units would be necessary. Assuming that some sediment would not properly respond to belt press dewatering (as prechecked via bench test) the area of appropriate application may cover one half of the dredging sites where a chemical contamination exists within the sediment.

From an overall problem-solving point of view or investment in resources, sludge dewatering belt presses for U. S. muncipal treatment plants are being installed at a rate of 80 per year. Thus, by comparison, 50-100 belt presses for dredging applications are similar in magnitude.

It has been well documented by researchers that any chemicals present in sediment are complexed and associated with the finer particulates (8). Thus, higher belt press solids capture is necessary for total confinement. Experience to date with coal tailings shows a 98 percent plus solids capture rate. Polymer dosage rates are normally set such that a slight excess of polymer is used to sustain proper performance. This excess polymer selectively associates with the finer particulates that pass through the belt media. Repeated testing shows that these filtrate solids agglomerate and separate out in less than 30 min. Thus, filtrate clarifier effluent is reused as belt washwater and the balance may be discharged directly to the receiving stream within discharge standards. The polymer-enriched filtrate solids settle out to 5 percent of original volume and are pumped directly to the upper drain deck and reintroduced with raw slurry. Thus, confinement is complete.

Figure 12 illustrates the conceptual barge-mounted belt press systems. Dewatering has been incorporated into a dustpan or cutter head barge as these are the "real workhorses of both private and Federal dredging fleets" (1). Obviously, the system could be adapted to pneumatic dredging for deeper harbor dredging as perfected and practical in Japan (1). Note that the barge receiving the dewatered cake would be sized to receive an 18-hr cake production, or 360 to 540 tons (dry solids basis). Energy for the dewatering system would be 20 hp (exclusive of pumping). This is probably equal or half that currently used to pump the slurry from barge to shore.

An alternate to the barge-mounted concept may be an on-shore dewatering facility using the "mudcat" type dredge, positioned at or near the final landfill site. Thus, slurry would still be piped to shore. Where space is too limited for slurry impoundment and long-term separation, the 83 percent volume

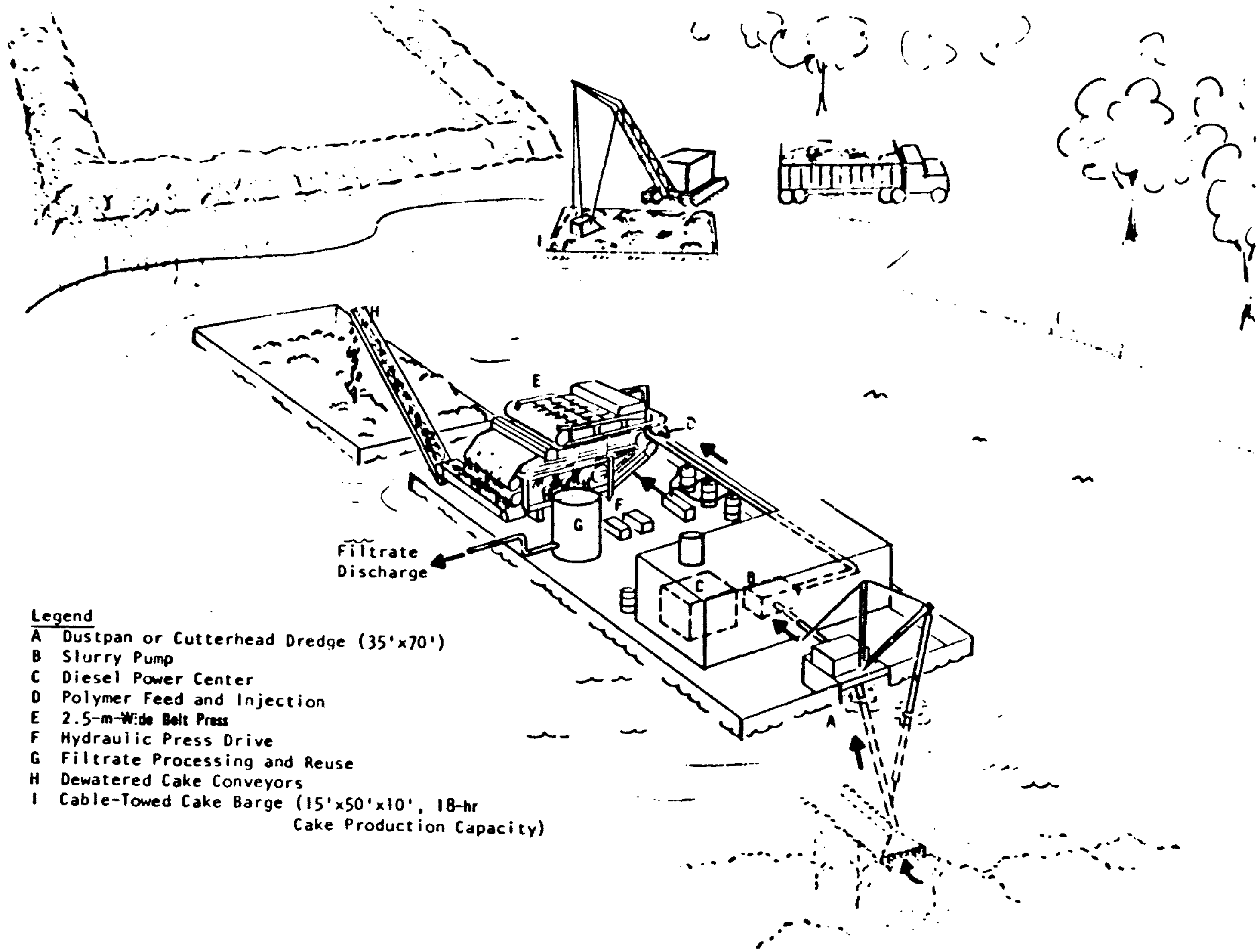

Figure 12. Conceptual barge-mounted belt press dredging system

reduction and immediate production of a high quality filtrate would satisfy environmental concerns. The dewatering system might be truck mounted to facilitate shorter slurry pipe transport distances, e.g., relocating parallel to a river dredging operation, week by week.

DEWATERING IMPACT ON CONTAMINANT CONCENTRATION

The chemical contaminant concentrations present in the dredgings will increase as dewatering proceeds. For example, if cadmium were present at 10 mg/ℓ in the pumped 15 percent solids slurry, the following example at a 400-gpm treatment rate is appropriate:

a. Hourly processing rate is 24,000 gal or, at a specific gravity of 1:1 and 15 percent solids, the total weight is 220,000 lb/hr, containing 33,000 lb solids per hour (throughput of 16.5 tons/hr).

b. Assume 10 mg/ℓ cadmium is present, or 2.2 lb cadmium.

c. Final cake concentration is 70 percent solids, or 21,000 gal water was removed per hour, or 47,000 lb total weight remain as cake per hour.

d. $\frac{220{,}000 \text{ orig.}}{47{,}000 \text{ remaining}} \times 10 \text{ mg/}\ell = 46.8 \text{ mg/}\ell$ cadmium present.

Thus, the heavy metal content is increased and further treatment of the stabilized cake may be necessary for permanent environmental compatibility.

DEWATERED DREDGING HANDLING AND PROCESSING ALTERNATIVES

After achieving an 83 percent volume reduction and a 70 percent stabilized cake, several alternative management practices may now be economical.

Dike material

The dewatered dredge cake can be used immediately for dike material to provide additional storage capacity (8). Here a split barging system could be used, where dewatered cake could be barged to form the dike and then slurry could be piped to the diked area.

Chemical fixation

Two-part chemical fixation--cement followed by sodium silicate--offers permanent encapsulation and pH stabilization for a wide range of contaminants, at high concentration. This fixation process is in full-scale practice for drilling muds, sewage sludge, and refinery sludge. Economics are directly proportional to volume treated. Thus, dewatering plays a vital role in achieving economical operation. In some cases, chemically fixed dewatered dredged material may form the barrier walls and bottom liner and dewatered unfixed solids could be contained. As an alternate, unfixed dewatered solids would be spread and a portion of the solids would be fixed and used as a capping, barrier protection at the end of the day.

Then longer range, high rate uptake biomass crops such as hyacinth or cattails or new mutant woody species would be harvested and assayed until contaminants in the cell tissue dropped to safe environmental levels. Toxic metal uptake into wetland plant biomass (cattail and willow) has been documented in several contracts with the Federal Department of Transportation. These projects sought to determine effects of highway stormwater runoff pollutants (metals, hydrocarbons, salts) on receiving water ecosystems. Metals concentration factors between sediment/soil, and vegetative components such as roots, rhizomes, shoots, stems, and leaves were determined (9).

CONCLUSIONS

Current practices in belt press coal dewatering suggest that similar success can be achieved on a portion of dredgings extracted from U. S. rivers and harbors. Combinations of advanced technology in computer structural modeling, high molecular weight polymers, and improved filter belt life are now available for the filter press process.

Near term application may exist for dredged slurries contaminated with chemicals because:

a. Volume reduction up to 83 percent would permit more positive control and confinement of the dewatered cake in designated landfill areas.

b. Containment of the chemicals within the solids and direct discharge of the filtrate is possible.

c. Reduction of a portion of the 55 million cubic yards to 9.5 million yards may accelerate the rate of dredging at reduced cost.

The 2.5-m modular belt press can be applied to a number of site-specific dredging scenerios:

a. Adapted for off-shore barge-mounted systems, for dustpan, cutter head, or deeper pneumatic dredging.

b. On-shore, semifixed where an immediate dike or berm formation is required.

c. Truck mounted, with week-to-week movement paralleling river dredging.

d. Confined, shallow mudcat type dredging and dewatering.

Specific bench test technology has been developed to define the proper site-specific applications.

Volume reduction achieved by dewatering can then add certain options to the overall dredging management program:

a. Chemical fixation where necessary.

b. Prolonged fill life of existing adjacent impoundment areas.

c. More immediate seasonal cropping or revegetation.

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DISPERSION OF SEDIMENT RESUSPENSION
CAUSED BY DREDGE OPERATION

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ABSTRACT

As a working model of dispersion of sediment resuspension caused by dredge operation, a model of turbidity levels according to distance from the dredge is useful. The level of turbidity near the sea bottom is estimated to be 5 ppm at a distance of 100 m and 3 ppm at 200 m from the dredge. Also, the level of turbidity near the water surface never exceeds that at the sea bottom. Therefore, it is not believed that dredging work will make a wide area of the sea turbid.

INTRODUCTION

Dredging work is indispensable in the excavation of waterways and the construction of harbors. However, dredging work causes sediment resuspension. Whether or not the resuspension develops turbid seawater on a large scale has not been proven. If the turbidity is dense and long lasting, it might endanger the life of fish and seaweed. It is desirable to predict the existence of this threat by analytically determining the dispersion of sediment resuspension caused by dredge operation; however, the present level of technology falls short of this goal. Therefore, the measured data taken from actual dredging work must be used in these predictions.

The following three companies belong to the Japan Dredging and Reclamation Engineering Association and each have agreed to make observations relative to the dredging work of one of their recent projects:

a. Penta-Ocean Construction Co., Ltd.
b. Toa Harbor Works Co., Ltd.
c. Toyo Construction Co., Ltd.

The results of their observations will be published as a technical paper in the near future, but the writer will give some thought to the problems by referring to the unpublished reports (1-4) with approval of the three companies.

Bottom sediments in these dredging works were not toxic; however, their research findings may still be of use in dredging toxic bottom sediments.

NATURAL CONDITIONS OF THE DREDGING SITES

Table 1 describes three dredging projects chosen for observation by the three companies. The locations are shown in Figure 1.

TABLE 1. DREDGING PROJECTS

Project No.	Location	Purpose of Work	Nature of Bottom Sediment	By Order of	Contractor
1	Imari Bay	Anchorage renovation	Clay	Saga Prefecture	Pena-Ocean Construction
2	Osaka Bay (Hannan Port)	Digging of reclamation	Silty clay	Osaka Prefecture	Toa Harbor Works
3	Osaka Bay (Osaka Port)	Quay base construction	Clay	Osaka City	Toyo Construction

All of the dredging sites are located in close sea areas with mild tidal currents and low permanent currents. Figure 2 shows the tidal currents in Imari Bay and the site of dredging project No. 1. There are two mouths to the bay, east and west, and the current flows from the west mouth to the bay interior and to the east mouth at rising tide, and vice versa, at falling tide. Overall, current directions are complicated by the influence of the topography. The current speed is as low as 10-17 cm/sec on the upper stratum, and at most 5-15 cm/sec on the bottom stratum.

Dredging projects Nos. 2 and 3 were conducted in the eastern part of Osaka Bay where the tidal current is as low as 25 cm/sec or lower and the current directions vary greatly according to the day. The only exception is when the tidal current passes the mouths of the bay. Otherwise, the current velocity is constant as shown in Figure 3.

Most dredging projects in Japan occur in a tidal current similar to those in Imari and Osaka Bays. In those sea areas, the dispersion of the substances is likely to be strongly affected by unpredictable flow velocity. Therefore, a theoretical treatment of dispersion is out of the question, and only a deduction through probability based upon the measured values is possible.

The grain-size characteristics of bottom sediments at the dredging sites are shown in Table 2. They are predominately clay and are easily suspended in the water column when disturbed.

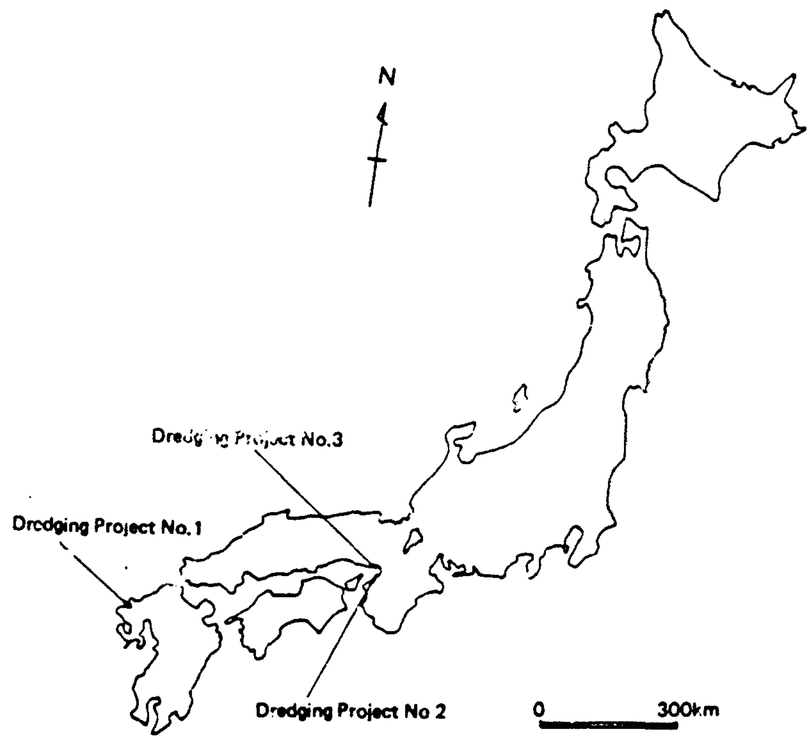

Figure 1. Locations of dredging projects

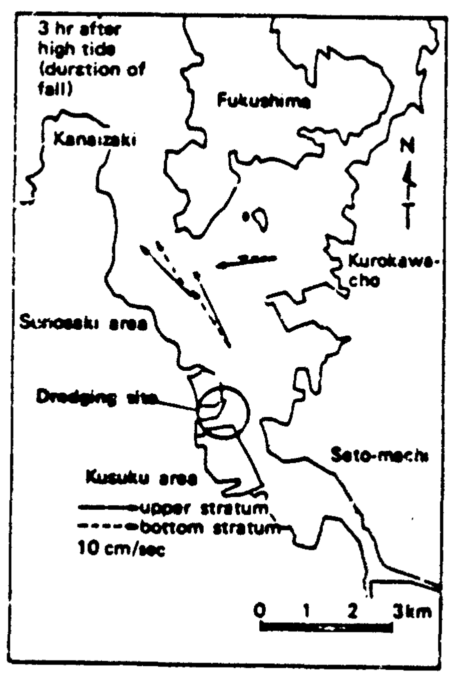

Figure 2. Tidal currents in Imari Bay

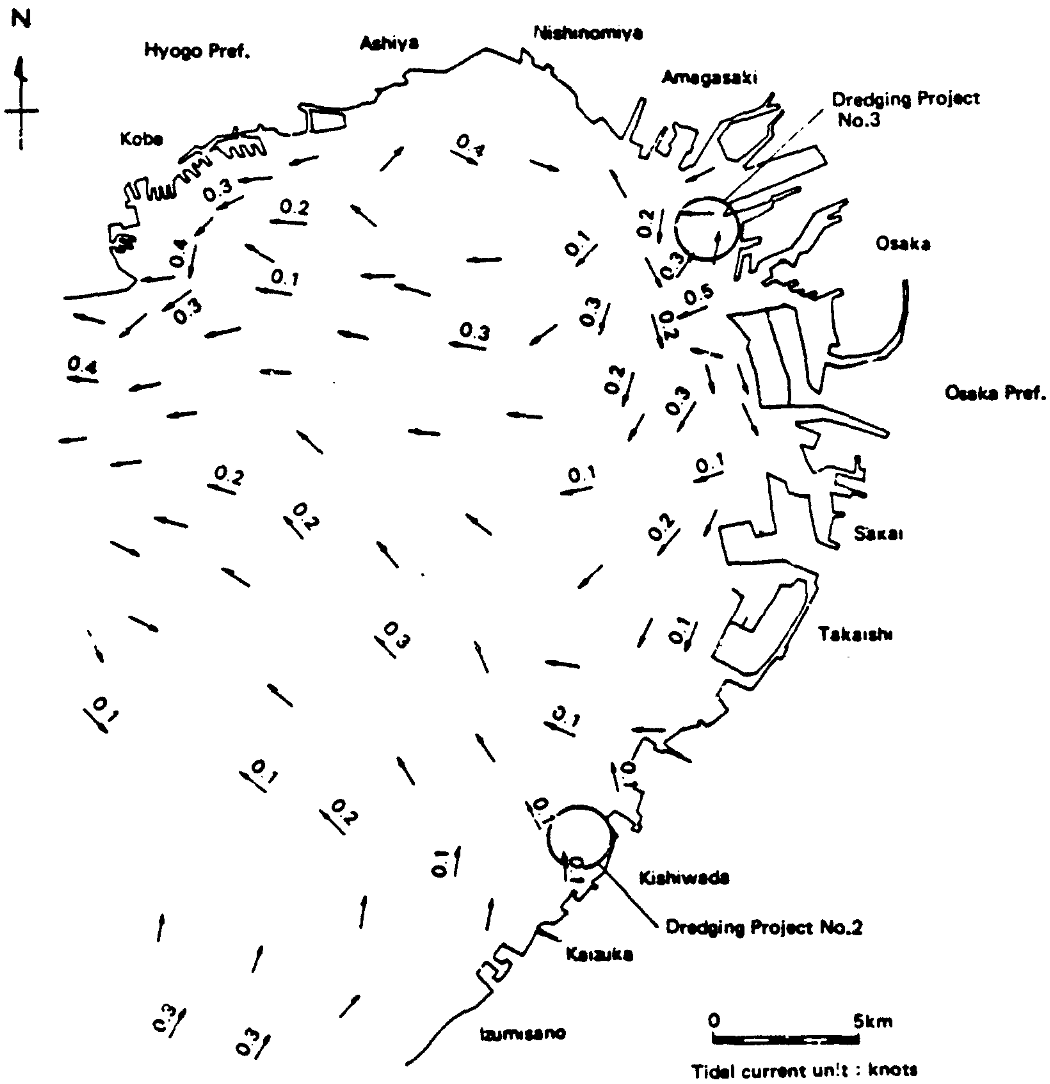

Figure 3. Tidal currents in the eastern part of the Osaka Bay where current is the strongest

TABLE 2. GRAIN SIZE OF THE BOTTOM SEDIMENTS AT THE DREDGING PROJECTS

Project No.	Location	Under 0.075 mm, %	Under 0.005 mm, %
1	Imari Bay	94.5	47.2
2	Osaka Bay (Hannan Port)	58.3	26.6
3	Osaka Bay (Osaka Port)	--	55.6

SPECIFICATIONS OF THE THREE DREDGING PROJECTS

Outlines of the dredging projects are shown in Table 3.

TABLE 3. SPECIFICATIONS

Parameter	1	2	3
Dredging period	Oct '82-Mar '83	Sep '82-Jul '83	Aug '82-Jan '83
Observation time	Jan '83	May '83	Nov '82
Dredge	D-3,000 PS	D-4,800 PS	D-4,000 PS
Total soil volume, m^3	636,380	730,571	551,800
Dredging depth, m	5.0-8.3	11.0-12.0	12.0-18.0
Dredged sediment thickness, m	1.0-2.0	1.7-2.6	0.5-2.0
Pumping volume, m^3/hr	5,600-6,300	9,100-9,600	4,500-5,700
Cutter revolution, rpm	12	17.6	16
Swing speed, m/min	8,12,18	4.4-6.1	4-21
Swing distance, m	80-90	82	56-85

Note: Values for dredged sediment thickness, pumping volume, cutter revolution, swing speed, and swing distance represent those at the time of turbidity observation.

TURBIDITY OBSERVATIONS AT DREDGING PROJECT NO. 1

Dredging project No. 1 was slated to dredge 636,380 m^3 of bottom sediment in about 6 months. Turbidity observations were conducted during 4 days of actual dredging. As shown in Table 4, the afternoon hours of each day were spent in observation. During these 4 days, six observation cases were planned, each case being slightly different from the others in the dredge operating conditions. The time spent for each case was 1.0-1.5 hr. The differences of the operating conditions were in the swing speed and the dredged sediment thickness.

The operating time of a dredge consists of two alternating periods: the dredging period in which the dredging by cutter takes place, and the advancing

TABLE 4. OBSERVATION SCHEDULE

Date	Observation Case and Time	
Jan. 18		B-1(14:17 to 15:47)
Jan. 20	A-1(12:56 to 13:56)	B-2(15:43 to 16:43)
Jan. 21	A-2(14:51 to 16:21)	B-3(17:03 to 17:43)
Jan. 22		B-4(16:14 to 17:14)

period in which no dredging is conducted but spuds are driven. Each observation case was scheduled to cover at least three consecutive dredging periods.

From among the many items observed, two are discussed herein: measurement of turbidity in the vicinity of the cutter, and measurement of the turbidity dispersed into the sea around the dredge. In the vicinity of the cutter, the measuring stations are fixed at the tip of the ladder with a frame, where the turbidity meters are set, as shown in Figure 4. In each observation case, the turbidity was measured six times during the dredging period. The average of the measured values taken at each station is as stated in Reference 2, of which the maximum was 1,313 ppm. Considering that this was the average value, the turbidity in the vicinity of the cutter could be said to have been quite high.

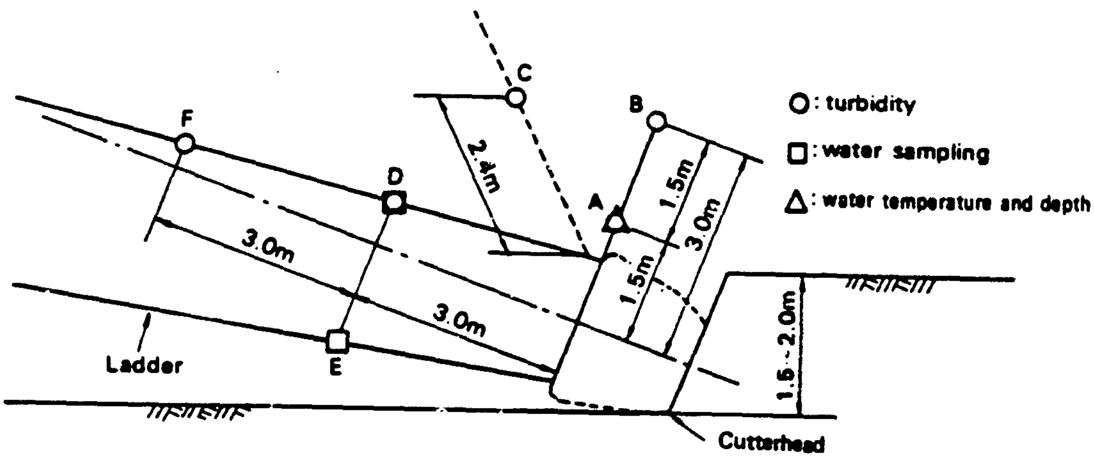

Figure 4. Locations of measuring station

For the measurement of the turbidity dispersed into the sea around the dredge, Figure 5 shows the positions of the measuring station. In each case, two small boats circulated around the 18 stations shown in Figure 5 and measured the turbidity at each station using a meter thrown into the water at the

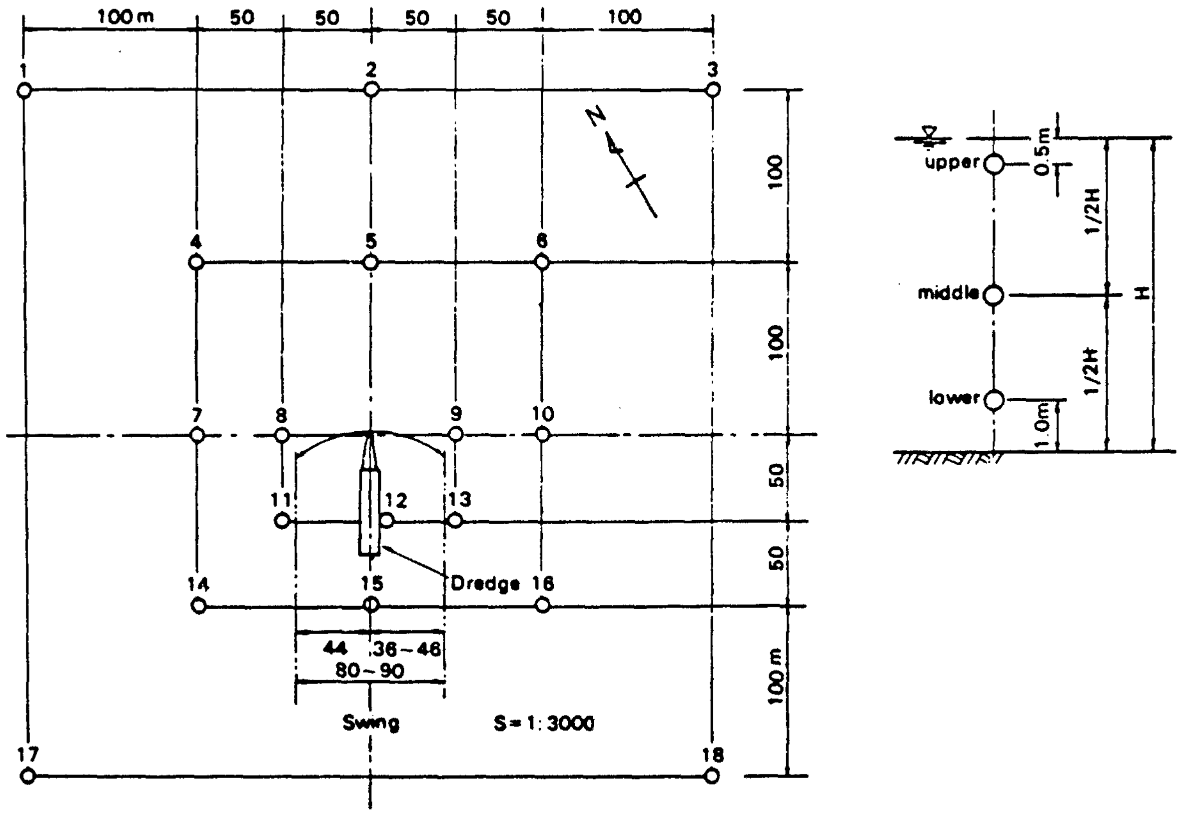

Figure 5. Locations of measuring stations (Dredging Project No. 1)

different depths. One circuit of the 18 stations by the boats took about 20 min and three circuits were made in each case.

For the purposes of this study, the measuring stations were divided into three groups according to the distance from the dredge. Stations 8, 9, 11, 12, and 13 were nearest to the dredge and compose Group A. The distance of each from the dredge is about 50 m. Group B contains stations 4, 5, 6, 7, 10, 14, 15 and 16, all about 100 m from the dredge. The remaining stations, 1, 2, 3, 17, and 18, belong to Group C, and are about 200 m from the dredge.

Table 5 shows the results for the three groups. Turbidity is shown by parts per million, representing suspended solids value, which is the value reached by deducting the estimated background value from the measured value. Comparison of these values with those in the vicinity of the cutter shows how the dispersion has decreased the turbidity.

It can be seen from Table 5 that the turbidity of the lower stratum (which is nearest to the sea bottom) gradually decreases both in maximum and mean values as the distance from the dredge increases. On the other hand, the turbidity of Group C shows a maximum value of 27 ppm and a mean value of 2 in the upper stratum. This shows that the large distance of 200 m lessens the overall turbidity considerably even though there was sporadic high turbidity in the area.

TABLE 5. TURBIDITY CAUSED BY DREDGING PROJECT NO. 1
AT VARIOUS DISTANCES FROM THE DREDGE

Group	Distance, m	Stratum	Number of Samples	Turbidity Max. ppm	Turbidity Mean ppm
A	50	Upper	66	6	2
		Middle	66	7	2
		Lower	66	61	6
B	100	Upper	127	19	2
		Middle	127	18	2
		Lower	127	27	3
C	200	Upper	82	27	2
		Middle	82	14	2
		Lower	82	14	2

Note: "Distance" means distance from the dredge.

Figure 6 shows changes in turbidity versus time in the average of each observation group. The changes in turbidity are quite similar between Group B and Group C at various depths in the upper and lower stratum. Although the range of change was less than 6 ppm and is not very large, it indicates the variance in dredging operations.

TURBIDITY OBSERVATIONS AT DREDGING PROJECT NO. 2

Dredging Project No. 2 was slated to dredge 730,000 m^3 of bottom sediment in about 10 months, during which three consecutive work days were set aside for the observation of turbidity around the dredge. Several observations were carried out in connection with turbidity, but several hours of the last day were used for investigation of the dispersion of turbidity.

This survey was conducted from 15:13 to 16:10 on May 12. The locations of the measuring stations are shown in Figure 7. At each of the stations, turbidity of the three strata as shown in the figure was measured by lowering the read-out turbidity meter from a sm˙˙l survey boat circling around each station. These measurements were taken three times during the day and three data samples were collected at each station.

For purposes of this study, the measuring stations were divided into two groups based upon distance from the dredge. Group A includes stations 4, 5, 6, 8, 9, 10, and 11 which were about 50 m distant from the dredge. The remaining stations, 1, 2, 3, 12, 13, and 14, which were about 100 m from the dredge, are classified as Group B. Background turbidity of this sea area was estimated from measured data to be 3 ppm. Table 6 shows the results of observations and calculations. The results were calculated by deducting the background values of 3 ppm from the measured values reported in the Reference 3. By checking the mean values, it is noted that turbidity returns to the

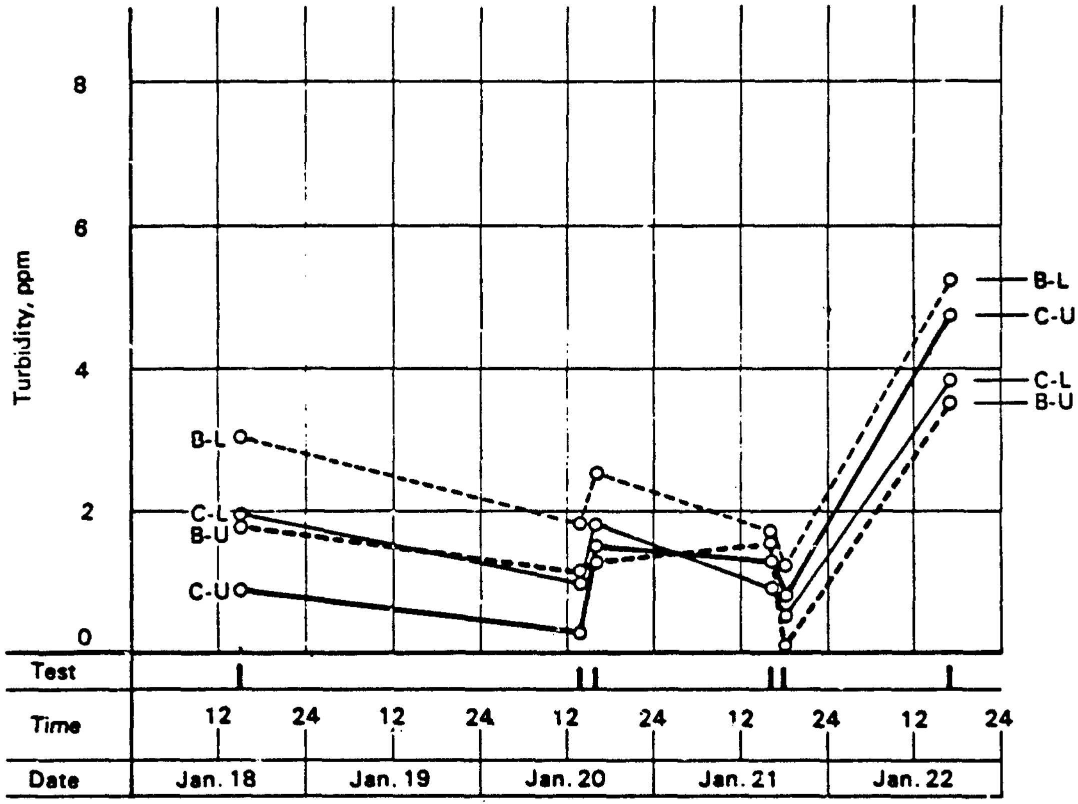

Figure 6. Changes in turbidity (Dredging Project No. 1)
B-L means Group B, lower stratum; C-U means
Group C, upper stratum, etc.

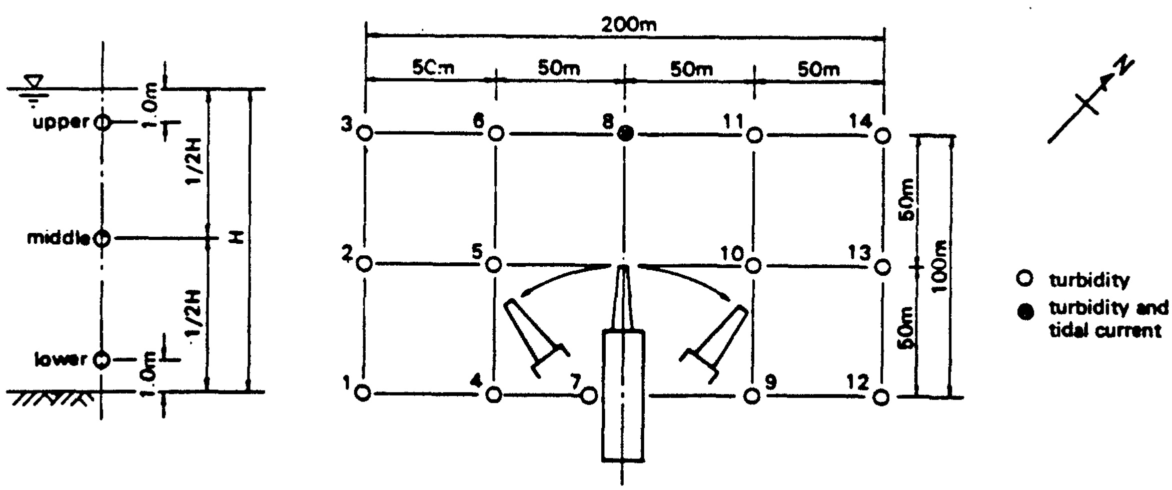

Figure 7. Locations of measuring stations (Dredging Project No. 2)

TABLE 6. TURBIDITY CAUSED BY DREDGING PROJECT NO. 2
AT VARIOUS DISTANCES FROM THE DREDGE

Group	Distance, m	Stratum	Number of Samples	Turbidity Max. ppm	Turbidity Mean ppm
A	50	Upper	21	2	0
		Middle	21	5	2
		Lower	21	6	3
B	100	Upper	18	1	0
		Middle	18	3	2
		Lower	18	4	2

Note: "Distance" means distance from the dredge.

background value near the surface at 50 m or beyond. The turbidity at the middepths and bottom is only slightly over the background value at the 50-m or 100-m distance. The maximum turbidity was 6 ppm in Group A and 4 ppm in Group B, both appearing near the sea bottom.

TURBIDITY OBSERVATIONS AT DREDGING PROJECT NO. 3

Dredging Project No. 3 was slated to dredge about 550,000 m^3 of bottom sediment in about 4 months, during which two consecutive days were set aside for the observation of dispersion of turbidity. The observations were conducted during the afternoon hours while the dredge was under operation. At the start of the survey, three small survey boats began circulating around the 28 stations shown in Figure 8 measuring the turbidity at each 1 m of depth down to the bottom. Table 7 shows the observation schedule. As shown in

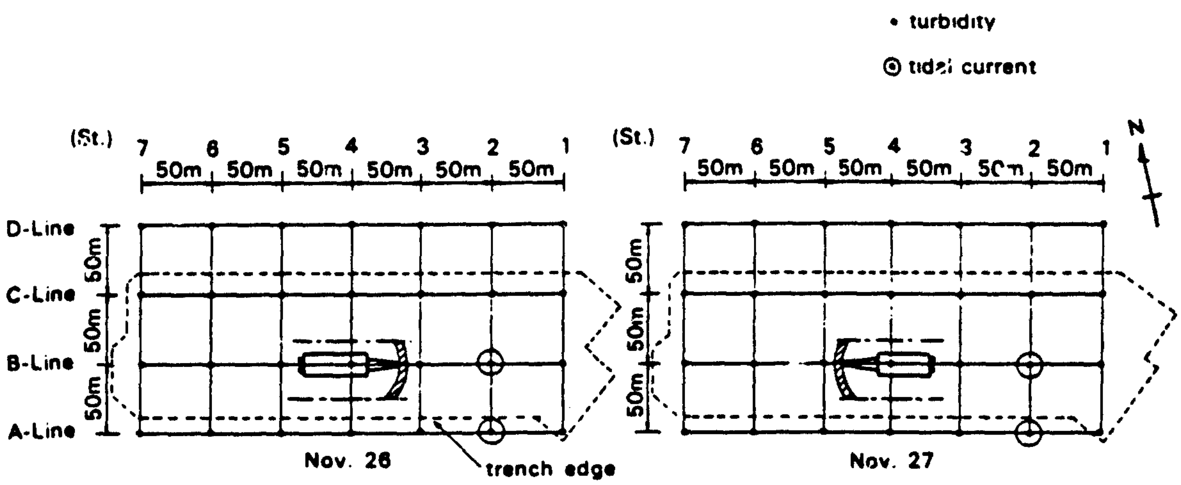

Figure 8. Locations of measuring stations (Dredging Project No. 3)

TABLE 7. OBSERVATION SCHEDULE

Date	Order of Test	Time
Nov. 26	1	13:40-14:20
	2	14:40-15:10
	3	15:10-15:40
	4	15:30-16:00
Nov. 27	1	13:20-14:00
	2	14:00-14:40
	3	14:30-15:10
	4	14:50-16:10
	5	15:40-16:20

Table 7, nine tests were conducted in the 2 days. Although the direction of the dredging on November 27 was opposite to that on November 28 as shown in Figure 8, the distance from the dredge to the observation stations can be regarded as unchanged throughout the observation period.

The operation period of a dredge consists of the dredging period and the advancing period; Table 8 shows this arrangement relative to Project No. 3. One observation time contained one or two dredging periods. As shown in Figure 8, station 4B was located nearest to the dredge. The observation results revealed that the turbidity around B-4 near the sea bottom was quite high. In this area the turbidity meter was scaled out four times out of nine, showing that the turbidity exceeded 500 ppm.

For purposes of this study, the 27 measuring stations excluding 4B, were divided into three groups according to the distances from the dredge. Group A was about 50 m from the dredge, containing stations 3A, 4A, 5A, 3B, 5B, 3C, 4C, and 5C. Group B was about 100 m from the dredge and contained stations 2A, 6A, 2B, 6B, 2C, 6C, 2D, 3D, 4D, 5D, and 6D. Group C was located about 150 m from the dredge and contained stations 1A, 7A, 1B, 7B, 1C, 7C, 1D, and 7D.

The survey demonstrated the turbidity at numerous positions and varying depths as shown in Table 9. It has become clear that the turbidity of 500 ppm and more at stations nearest the dredge was lowered to 72 ppm or less at 50 m from the dredge, and to only slightly over the background value at a distance of 150 m.

Figure 9 shows changes in turbidity versus time. In the figure, the curves of Group B and C (100 m and 150 m) are rather flat, showing that dispersion of turbidity has become steady.

TABLE 8. DREDGE OPERATING CONDITIONS AND TIME SCHEDULE FOR VARIOUS OBSERVATIONS

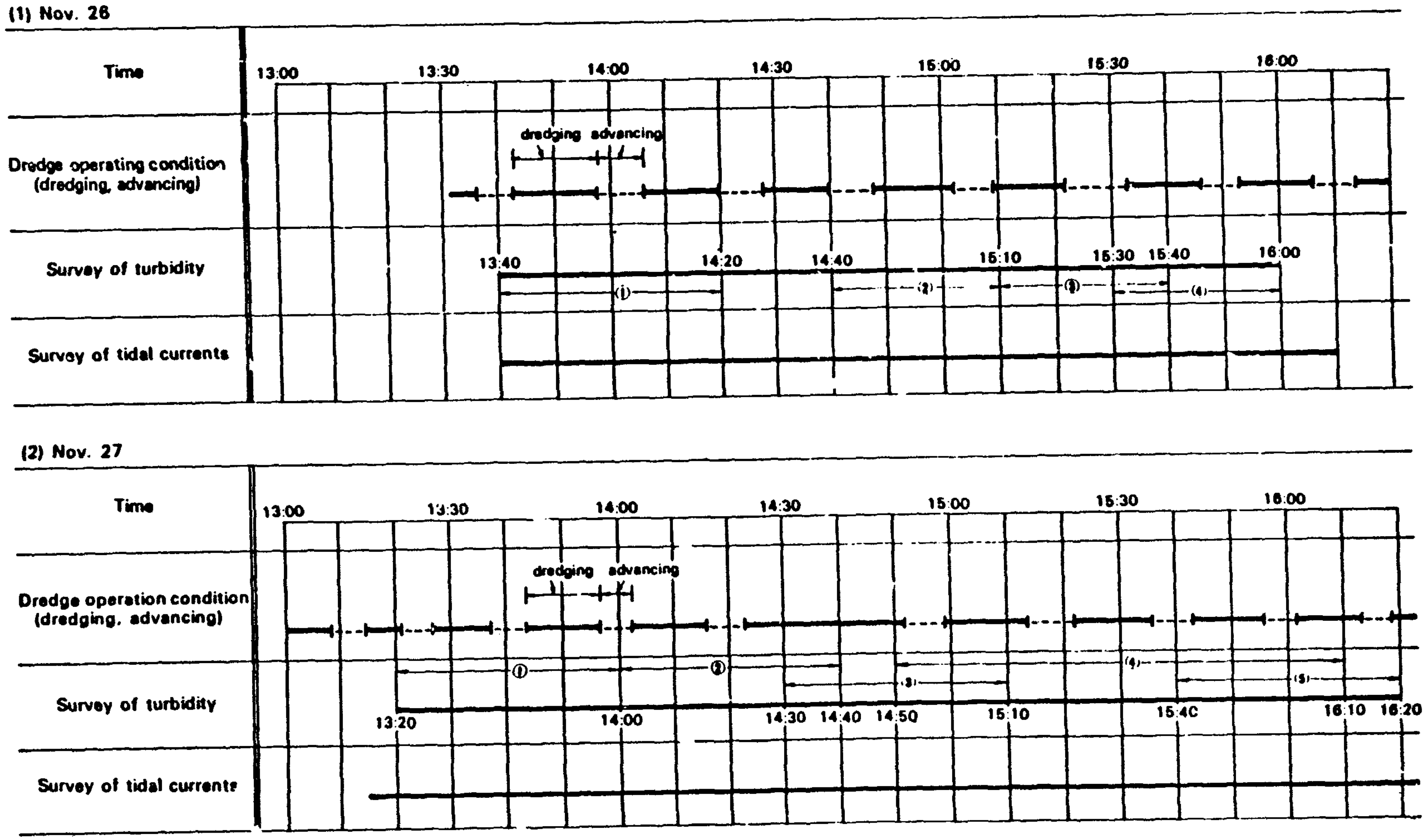

TABLE 9. TURBIDITY CAUSED BY DREDGING PROJECT NO. 3 AT VARIOUS DISTANCES FROM THE DREDGE

Group	Distance, m	Stratum	Number of Samples	Turbidity Max. ppm	Turbidity Mean ppm
A	50	Upper	72	2	0
		Middle	72	9	1
		Lower	72	72	6
B	100	Upper	82	5	1
		Middle	82	4	0
		Lower	82	17	1
C	200	Upper	58	5	1
		Middle	58	2	0
		Lower	58	12	1

Note: "Distance" means distance from the dredge.

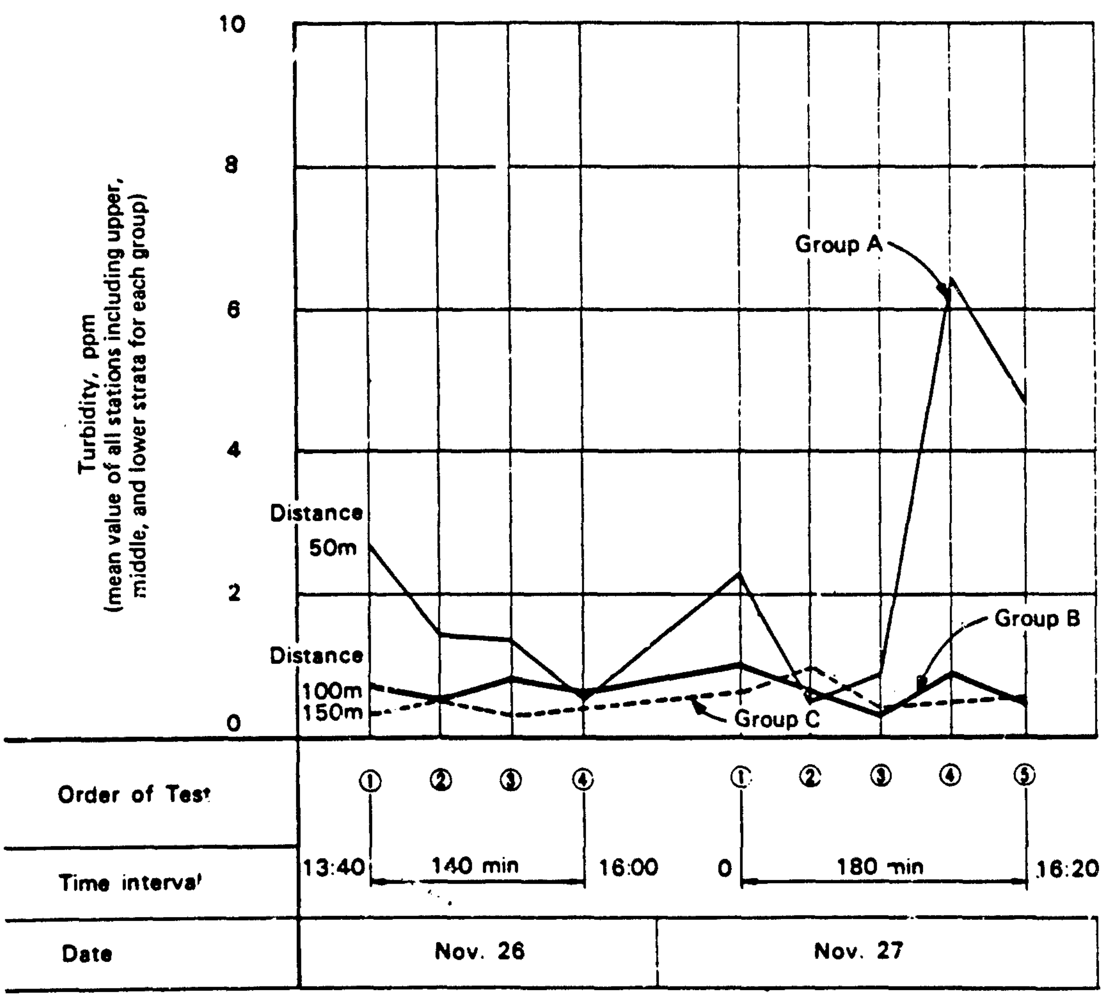

Figure 9. Changes in turbidity measurements (Dredging Project No. 3)

PROPOSED DISPERSION MODEL

When comparing the results of the three dredging projects, some generalities can be seen concerning the distribution of turbidity in various areas of the sea surrounding the dredge. Figure 10 is a comparison of turbidity near the sea bottom; this figure shows that at a distance of 100 m from the dredge the turbidity does not exceed more than 3 ppm over the background value in any observation. The curves in Figure 10 show that turbidity decreases to 2 ppm at a distance of 200 m. It is difficult to estimate the turbidity beyond 200 m, but the assumption of 1 ppm turbidity at a distance of 1 km from the dredge is not unreasonable.

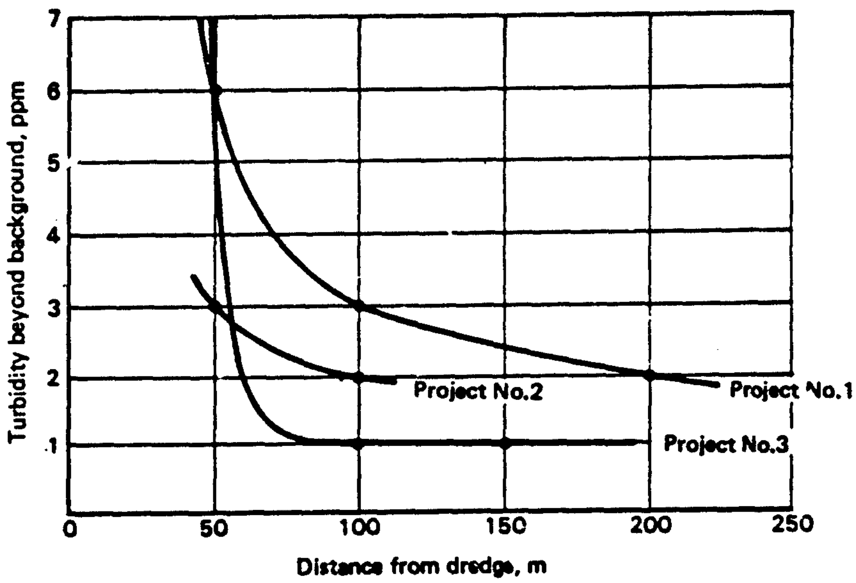

Figure 10. Mean value of turbidity near the sea bottom

A proposed dispersion model could make allowances for the turbidity mentioned above. According to this model, the mean value of turbidity at a distance of 100 m from the dredge and near the sea bottom would be 5 ppm over the background value, and 3 ppm at a distance of 200 m.

For turbidity near the water surface, the results of the three dredging projects showed that the mean value of turbidity did not exceed the value near the sea bottom. Therefore, according to the proposed model, the mean value of turbidity at a distance of 100 m and more from the dredge and near the water surface would be less than 3 ppm over the background value.

It may not be meaningful to compare the maximum values of the measured turbidity, but it is interesting to find a natural law in such a comparison. From that point of view, the comparison is shown in Figure 11.

Such maximum values sometimes appear locally and temporarily, and may indicate the size of deviation from the mean values of turbidity. Otherwise

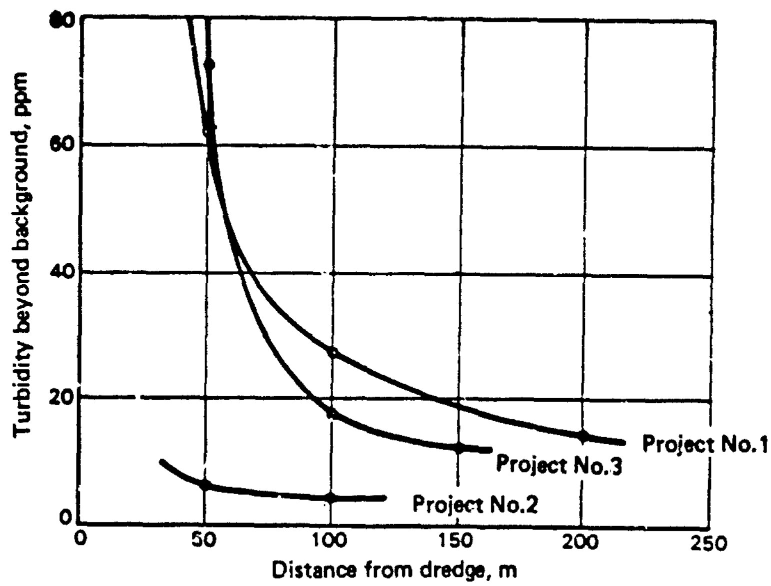

Figure 11. Maximum value of turbidity which temporarily appears at the sea bottom

they may appropriately indicate the characteristics of the dispersion phenomenon by the turbulent flow. Either way, they have negligible effects on living things; therefore, the proposed model contains no maximum value of turbidity, and only refers to its existence without numerical value.

The following conditions should be present before the proposed model can be used:

a. The work should be conducted in a wide and closed sea area.

b. The sea area should not have a strong and fixed sea current but rather a weak current with unsteady direction.

c. The bottom sediments to be dredged should be soft clay, containing more than 50 percent of particles less than 0.075 mm in diameter.

d. The dredge should be a 5,000 ps class or smaller.

e. The dredging work to be carried out should be of an ordinary nature.

The model may appear too bold of a proposition because it is based upon observations of only three dredging projects. However, since the literature (5, 6) concerning past examples of such observations is similar in nature, it can be said that the proposed model does not underestimate turbidity.

CONCLUSIONS

Since the dispersion of sediment resuspension caused by dredging depends on the turbulent flow of seawater, it is quite difficult to make predictions by applying a mathematical model. Therefore, the practical solution is to

show only an empirical model of turbidity distribution. Such a model cannot be expected to be accurate unless a statistical analysis is made by observing numerous instances of dredging. However, it is also true that to carry out observations of turbidity using numerous instances is a problem. This is a dilemma accompanying prediction of the dispersion of sediment resuspension.

Environmentalists claim that the effects of turbidity of the seawater are harmful to the life of fish and seaweeds. Therefore, it is necessary to secure the understanding of these environmentalists by fashioning an accurate model of the dispersion of sediment resuspension caused by dredging, in order to safely carry out dredging work to maintain the sound development of the economy. For that purpose, to have as many practical observations of turbidity as possible is a must to overcome all conceivable problems to achieve this end. The author sincerely hopes that this report will be of some help in realizing these goals.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Hiromichi Yamashita, managing director of Penta-Ocean Construction Co., Ltd., and Mr. Eisuke Sato, chief engineer of Toa Harbor Works Co., Ltd., for their cooperation and assistance in the course of compiling this thesis. Thanks also go to the staffs of the three companies who helped me in carrying out such troublesome work.

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AN ANTI-TURBIDITY OVERFLOW SYSTEM (ATOS) USED FOR REDUCING THE DISPERSION OF FINE SEDIMENTS FROM A DREDGE PLUME

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ABSTRACT

In 1976 at the World Dredging Conference in San Francisco, Calif., two Japanese authors, Ichiro Ofuji, Manager of IHI Special Vessels Design Department, and Naoshi Ishimatsu, an engineer in the same department, submitted a prizewinning technical paper entitled, "Anti-Turbidity Overflow System for Hopper Dredger." By the removal of air trapped in the overflow slurry from a hopper dredge, and the placement of the overflow below the waterline, reductions in visible surface plume effects were achieved by a factor of 40 in silty sands. The effects were not so noticeable in coarse sands. The U. S. Department of the Interior, Minerals Management Service (MMS), is responsible for managing the production of minerals from the Outer Continental Shelf. In an effort to further quantify the effects of installations of an ATOS on a dredge used for mining offshore, the MMS and the United States/Japan Cooperative Program in Natural Resources are preparing a test to take place in Shimonoseki Port in Northern Kyushu. The purpose of the test is to characterize the magnitude and behavior of turbidity plumes associated with a dredging operation with and without ATOS. Plume characteristics, including magnitudes in three dimensions--trajectory, density, and density gradients and suspended sediments--will be measured as a function of time. The test is planned for the spring of 1984 from the dredging vessel, KAIHO-MARU.

INTRODUCTION

Original U. S. interest in the Japanese-developed ATOS dates back to 1976 when Ichiro Ofuji (the inventor of ATOS) presented his award-winning technical paper on the subject at the 7th World Dredging Conference (WODCON VII) in San Francisco. Interest then transcended to the Department of the Interior's (DOI) Outer Continental Shelf (OCS) Mining Policy Task Force which formally recommended consideration of ATOS as a "mitigating control system" for installation on hopper dredges used in OCS mining. This recommendation also was

strongly supported by the Assistant Secretaries for Energy and Minerals and Land and Water Resources.

Now, through the continued interest and support of the United States/ Japan Cooperative Program in Natural Resources (UJNR), we have an opportunity to examine the ATOS in Japan and learn of its applicability to dredging for hard minerals, such as sand and gravel, on the OCS. It is felt that ATOS provides the basis for a mitigating control system that will be of great interest to those concerned with the environmental or fisheries implications of a large surface plume and the possible accumulation of a blanket of fine sediment settling out over a broad area of the seafloor.

CURRENT PLANS AND SCHEDULING

Under UJNR sponsorship, proposed joint testing of ATOS will involve interagency participation with the DOI Minerals Management Service (MMS) serving as the lead agency for DOI. A U. S. Scientific Team composed of four members--one each from MMS, National Oceanic & Atmospheric Administration (NOAA), U. S. Geological Survey, and the Corps of Engineers (CE)--and a U. S. Regulators Team of nine members, made up of representatives from MMS, NOAA, Environmental Protection Agency, CE, Fish and Wildlife Service, and the Bureau of Land Management. The U. S. Scientific Team will work with their Japanese counterparts in designing a test plan to satisfy the desired objectives of the ATOS experiment.

WHAT IS ATOS?

"ATOS" is the acronym for the Japanese-developed "Anti-Turbidity Overflow System" designed to prevent surface turbidity and widespread accumulation of fine sediments on the seafloor, commonly associated with conventional suction hopper dredge mining operations. The system, which is U. S. patented, can be readily installed on hopper dredges currently in service through simple modifications.

In developing the system, it was learned that during hopper filling and overflow, air bubbles with entrained sediment in the water cause the surface turbidity plume associated with hydraulic suction hopper dredging. Using the conventional overflow process, air is trapped in the mixture of water and fine sediment and then carries the particulate material to the surface when it rises in the form of bubbles. In effect, with a conventional overflow system, the rising air bubbles produce an "air-lift" or "flotation" effect on the suspended sediment particulates (Figures 1 and 2).

The ATOS, when adapted to a conventional suction hopper dredge, solves this problem simply by eliminating entrapped air and discharging the air-free water-sediment mixture below the waterline. The result is a relatively clear water column, no surface turbidity plume, and presumably only a small area of fine-sediment accumulation at the dredge site caused by the system's rapid suppression of particles (Figure 3).

Japanese tests in fine sand or silt show that ATOS reduces surface turbidity down to 10 ppm, or lower, in suspended solids concentration. This compares with a test result of over 400 ppm without ATOS.

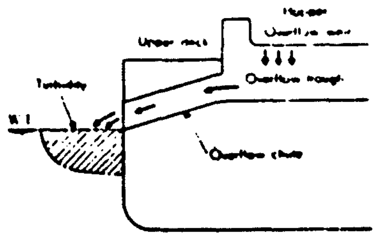

Figure 1. Conventional overflow system

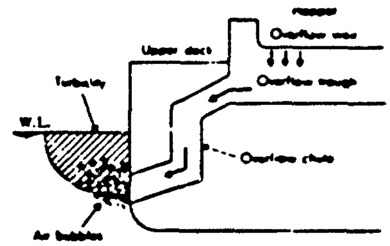

Figure 2. Conventional overflow system

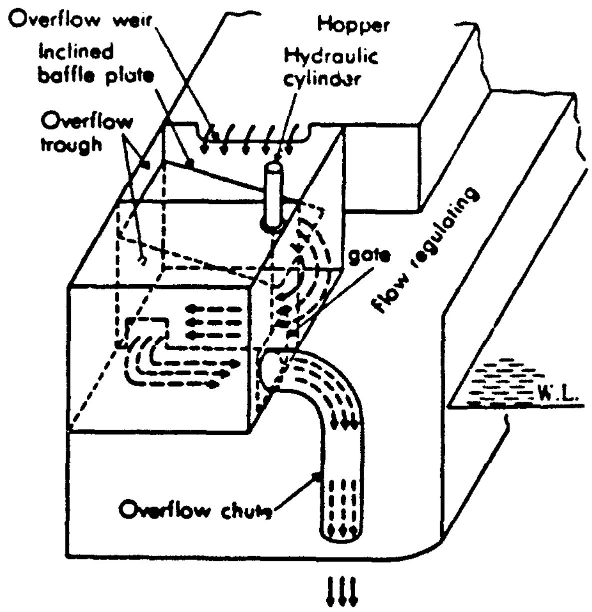

Figure 3. Anti-Turbidity Overflow System of the TOKUSHUN-MARU NO. 1

Other Japanese tests at a silty sand deposit show that ATOS can reduce the level of turbidity down to about 5 or 10 ppm. In these tests, the Japanese determined turbidity levels versus time and water depth.

Visual observation of changes in the surface turbidity plume, with and without ATOS, can be easily noted. The KAIHO MARU used in the test program is one of the large ATOS-equipped hopper dredges operating in Japanese waters, mainly by the Ministry of Transportation (Table 1).

The Japanese have also conducted extensive model tests of turbidity diffusion using a 1:20-scale actual model of the trailing hopper dredge, SEIRYU MARU, owned by the Ministry of Transportation. The model was towed at a constant speed while turbidity diffusion due to overflowing muddy water was recorded photographically by three 35-mm cameras, three underwater cameras, and a television camera. These model investigations contributed significantly to the ultimate design of ATOS, including the feature of discharging the hopper effluent through discharge pipes protruding 2 m below the ship's hull (1).

TABLE 1. MANUFACTURING RECORD OF ANTI-TURBIDITY OVERFLOW SYSTEM (ATOS) FOR HOPPER DREDGES

Dredge	Hopper Capacity, m^3	Owner	Delivery	Remarks
TOKUSHUN-MARU NO. 1	4,000	Tokushu Shunsetsu Co., Ltd.	1971	
KAIRYU-MARU	1,700	Japanese Ministry of Transportation	1974	
KAIHO-MARU	2,000	Japanese Ministry of Transportation	1975	
HAKUSAN-MARU	1,300	Japanese Ministry of Transportation	1978	With automatic control system
SUMBAWA	1,000	Indonesian Government	1978	
SEIRYU	1,700	Japanese Ministry of Transportation	1978	

JAPANESE VERSUS U. S. INTERESTS

Japan's offshore sand and gravel mining industry is the world's largest with offshore production of about 70 million tons per year or about 20 percent of Japan's total production of natural aggregate. Likewise, the Japanese do a considerable amount of dredging with large trailing suction hopper dredges in connection with creating harbors, navigation channels, and offshore islands. Some of these operations are in close proximity to fishing grounds or marine cultivation farms (for seaweed, pearls, or fish). Recognizing that turbidity from conventional hopper dredging operations could damage these resources, such operations are sometimes put under restriction or suspension. Now, with the installation of ATOS on these dredges, dredging can safely proceed in these areas without any restrictions.

Extensive testing and actual field application of ATOS by the Japanese have proved successful in solving these specific problems of the nearshore

environment. However, with concern over the surface plume's migration toward seaweed beds and cultivation farms, the Japanese concentrated their earlier studies on the plume at the sea surface, namely on surface turbidity diffusion. Now, with joint U.S./Japanese interest extending to sand-mining operations in the open-shelf environment, there is a need for determining what takes place at or near the seafloor, with and without ATOS, in terms of suspended sediment dispersion characteristics and the areal extent of the "blanket of fines" accumulating on the seafloor (2).

At a meeting of the Joint Scientific Committee, ATOS project, held in Tskuba, Japan, on 27 May 1983, it was resolved to carry out tests in May 1984 using the dredge KAIHO MARU operating in Kanman Channel at the Port of Shimonoseki in Northern Kyushu (Figures 4 and 5). Turbidity from the action of the draghead on the seabed will be examined in the experiment as well as turbidity from the hopper overflow discharge, with and without ATOS. Measurements of plume magnitudes in three dimensions, plume trajectory, plume density, and density gradients and suspended sediments, will be taken at selected points during the dredge operating cycle to characterize the magnitude and behavior of the plumes (Table 2). Background measurements at selected points will be taken before and after the tests.

It is hoped that sufficient data will be gathered to allow assessment of the value of installing ATOS equipment on dredges used for mining offshore to mitigate the formation of environmentally undesirable sediment plumes.

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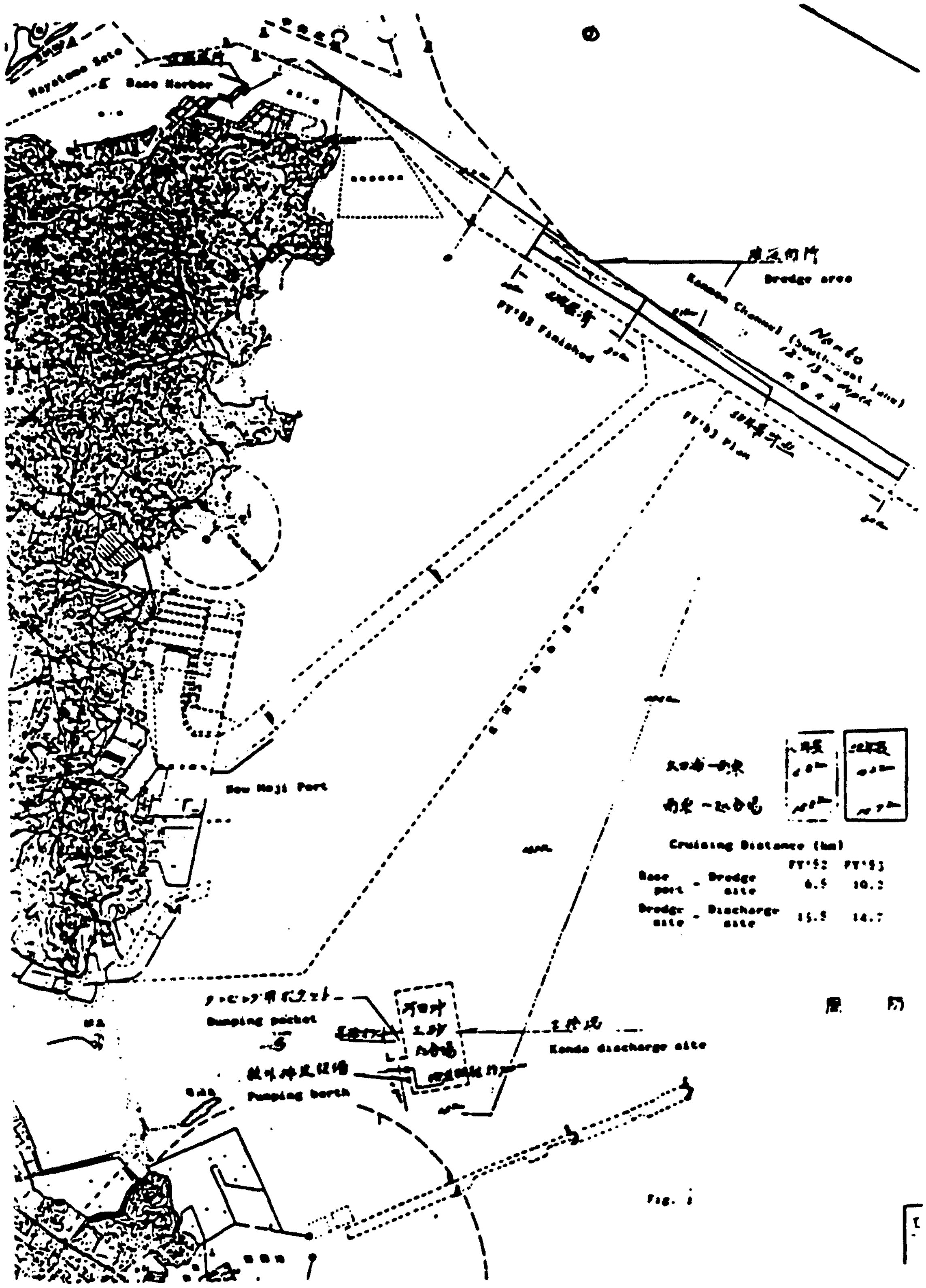

Figure 4. Location of ATOS tests

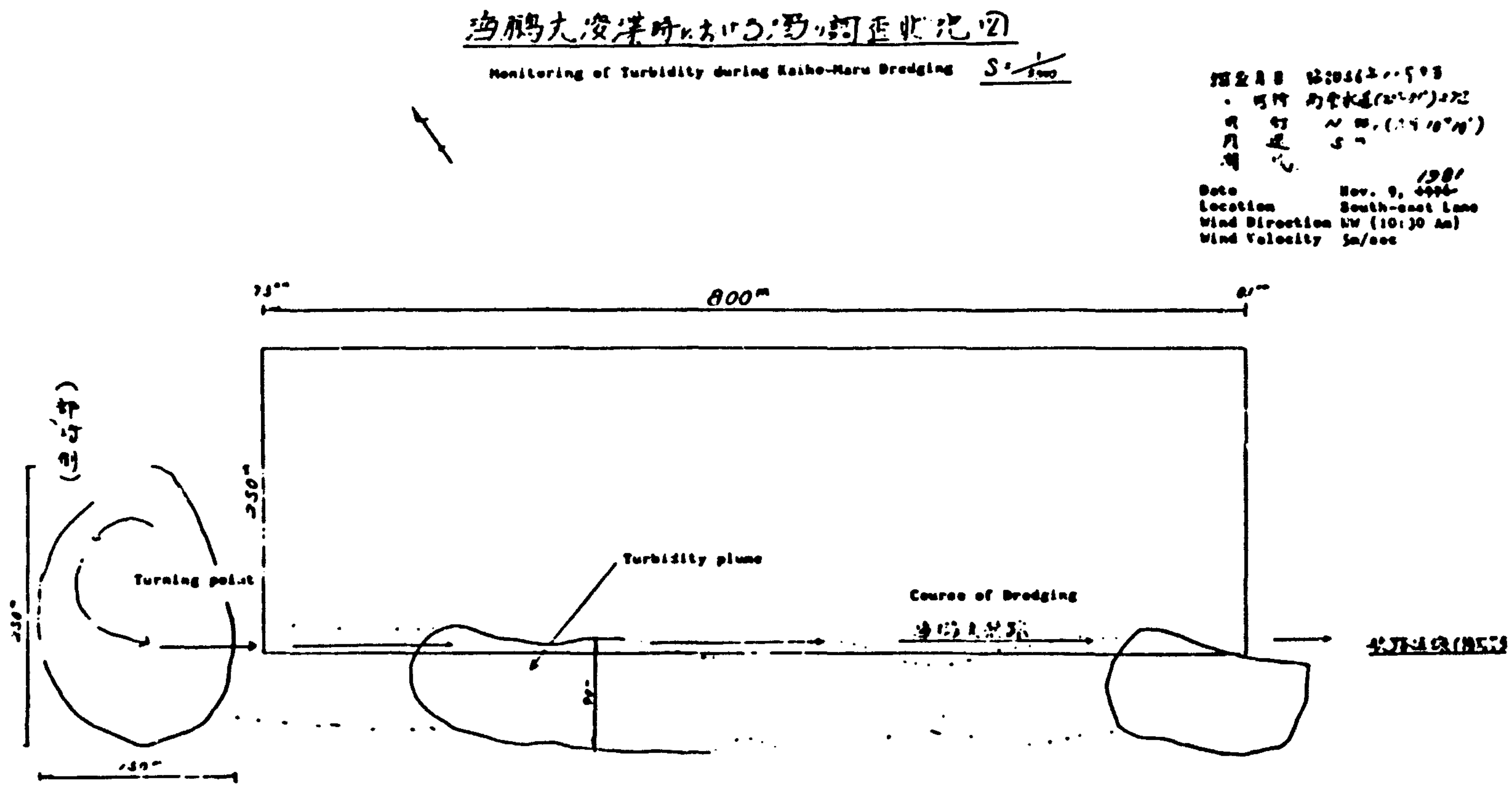

Figure 5. Monitoring of turbidity during KAIHO-MARU dredging

TABLE 2. MEASUREMENT PARAMETERS AND EQUIPMENT

Action/Objective	Measurement Parameters	Equipment
To characterize the magnitude and behavior of turbidity plumes associated with a dredging operation with and without ATOS. Using a Lagrangian approach, turbidity plume characteristics including: a. Magnitude (three-dimensional). b. Trajectory. c. Density and density gradients. d. Suspended sediments measured as a function of time.	At least two repetitions per discharge cycle of dredge and one after shutdown.	Three boats for plume transverses
	In plume, at each sample site through water column repetition: a. Suspended sediment (mg/ℓ). b. Time and time increment (sec) at and between sampling. c. Salinity and temperature (ppt and °C). d. Current velocity and direction (cm/sec).	Suspended sediment sampler bottles, Van Dorn type (4 each boat) Transmissometers (3) Portable current meter (1) Salinity and temperature measuring devices (possibly incorporated with Van Dorn samplers) (1)
	At selected points, as appropriate with time and conditions: a. Swell and sea state (period, height, direction). b. Wind velocity (cm/sec), direction. c. Tide stage. d. Depth (m).	Stop watches (4) Navigation equipment (mini-ranger type)
	Outside plume, control points, once per discharge cycle, at points to be selected: a. Ambient suspended sediment (mg/ℓ). b. Salinity and temperature. (ppt and °C). c. Current velocity and direction profiles. d. Swell and sea state (periods, height, direction).	Hand-held anemommeter (1) Communication (two-way radios) (5) Grab samplers (Shipek type) (3) Inductive salinometer (1)
	At dredge, point of discharge: a. Bottom surface sediments. b. Discharge material characteristics.	Light plane or tethered balloon with TV (1) Camera (1)

NEW TECHNIQUES DEVELOPED IN JAPAN FOR OIL SPILL CLEANUP

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ABSTRACT

In the last decade, the total number of reported water pollution incidents in Japan has decreased by 36 percent. Of these incidents, 80 percent are oil spills. Three oil recovery systems currently being used in Japan are discussed in this paper. The first one is an oil recovery system that uses aeration to separate the oil and the water. It is intended for recovery of low viscosity oil that spreads itself over the water surface as a thin film. The second, or rotary bucket oil recovery system, is used to clean up spills of high viscosity oil, like crude or heavy oil, which remains on the water surface in a thick layer. The third is a gelatinization recovery system that converts all types of oil into a semisolid consistency for easy mechanical recovery.

INTRODUCTION

Oil spills at sea are a worldwide concern. This concern is expressed by specific oil-spill-related environmental protection regulations established by international conventions and domestic laws in many countries.

Since the establishment and enforcement of oil spill regulations in Japan, the number of oil spills reported has steadily decreased. Yet, a considerable number of oil spills due to shipwreckage, collusion, or improper operation of ship's equipment will inevitably continue to occur in spite of these regulations and human efforts.

Oil from spills may float on the sea surface or exist suspended in the water below the surface. Wave action is capable of forming certain types of oil into "oil balls." Floating, suspended, and "oil balls" may drift ashore to contaminate beaches or sink to the sea bottom and damage the ecological environment.

This paper introduces new Japanese technology for recovering oil spills at sea.

CURRENT SEA POLLUTION IN JAPAN

Reported Incidents of Sea Pollution

Figure 1 shows the total number of sea pollution incidents reported in Japan between 1971 and 1980. As indicated in this figure, the total number of incidents has decreased yearly from its peak of 2460 cases in 1973, except for a slight increase in 1979. Despite a 36 percent reduction in the number of incidents, 1581 cases were still reported in 1980 and there is no guarantee that the number of incidents will continue to decrease in the future.

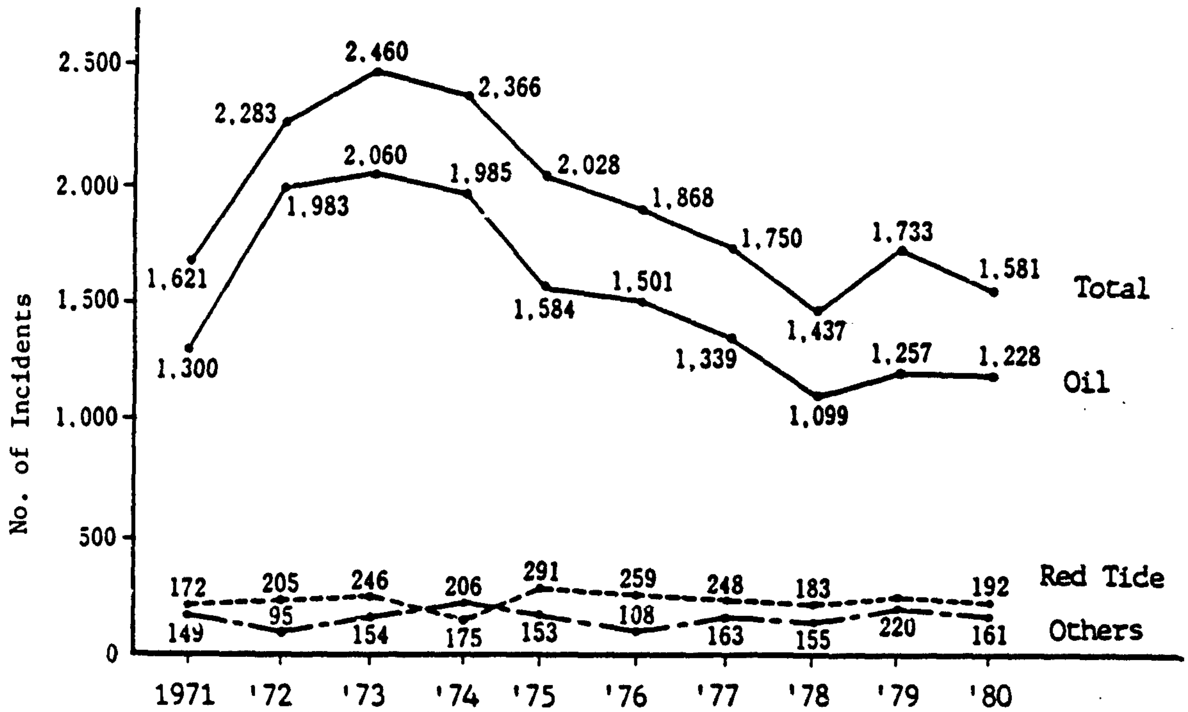

Figure 1. Reported number of sea pollution incidents in Japan, 1971-80 (1)

Among all cases of sea pollution, oil spills comprise the majority of incidents with 1228 cases in 1980 (78 percent of total incidents), followed by red tide with 192 incidents (12 percent of total), and all other 161 incidents, such as garbage disposal or industrial wastewater, accounting for 10 percent of total incidents.

Oil Balls

Around 1965, deterioration of the natural environment of beaches and sea coasts became a social concern as tarlike, adhesive solidified blocks of oil ("oil balls") drifted on the sea surface and reached some beaches on the southern islands of Japan. With the expansion of Japanese economy since 1965,

the number of such incidents has increased, causing damage to fishing grounds, seaweed farms, pearl cultivation farms, and recreational areas.

It is believed that an oil ball is generated through the effects of wave action on an oil-water mixture. The source of the oil could be dirty ballast water, tank cleaning water, sludge waste disposal at sea, or any number of other sources of oil in the marine environment.

The characteristics of an oil ball are listed in Table 1.

TABLE 1. CHARACTERISTICS OF OIL BALLS COLLECTED FROM BEACHES

Characteristic	Range	Mean
Specific gravity, 15/4°C*	0.79 - 0.925	0.856
Viscosity, 210°F cst**	13.05 - 28.61	18.88
Drifting point, °C	35.5 - 62.5	52.5
Coal, %	2.57 - 14.02	6.7
Mineral, %	0.00 - 7.41	1.36
Sulphur, %	0.089- 2.318	1.18
pH of oil	2.1 - 6.75	3.8
Total acid equivalent, KOH mg/g	2.36 -100.98	24.3
Foreign material, %	5.74 - 15.95	10.48

* Oil density (15°C)/water density (4°C).
** Centistokes at 210°F, nearly equal to cP (centipoise).

The majority of oil balls drifting on the sea surface are 5 to 6 mm in diameter, but can be as large as 40 mm. In comparison, the sizes of oil balls that reach beaches are generally larger, i.e., 10 to 50 mm in diameter in most cases, and, sometimes, even bigger balls, up to 500 mm in diameter, are observed (2).

The specific gravity of oil balls that reach the beaches is usually lower than 1.0. However, some oil balls containing gravel or sand with a specific gravity greater than 1.0 have also reached the beaches.

When drifting on the sea, oil balls extend over a wide area and form wide belts with varying lengths. Wind driven and tidal currents can transport the balled oil to coastlines far removed from the actual spill and deposit the oil along sandy and rocky shores.

Damage Caused by Heavy Crude Oil Spills

A recent report states that crude oil spills in the Persian Gulf spread at a rate of 100 to 300 m/hr. While the crude oil drifts on the sea surface,

the light, less adhesive and volatile oil separates from the heavier oils, spreads in a thin film, and, due to solar heat, vaporizes. After vaporization of the light oil, the crude oil becomes more dense and begins to sink and drift just below the sea surface.

The crude oil spilled in the Persian Gulf has a higher specific gravity (0.92) than other oils, such as Iranian light (S.G. 0.85). Due to its higher density (in relation to the specific gravity of seawater), the oil sinks and remains in the water at a depth greater than 50 cm below the surface. As oil spills continue to occur, it will become more probable that the more dense portions of crude oil drifting in the water will reach the nearby seacoasts or settle onto the sea bottoms resulting in widespread toxic deposits.

RECOVERY OF SPILLED OIL

Although it is almost impossible, at present, to vacuum all the large-scale oil spills, some technology for oil spill recovery is available and is practical for use in harbors or confined areas. This discussion deals with some of the technology developed in Japan.

Recovery System for Low Viscosity Oil

Among various recovery systems for low viscosity oil, the system that uses aeration to separate the oil from the water is a unique one. This system was developed by IHI for SOKAI and NO. 2 SOKAI, two self-propelled oil recovery ships with catamaran hulls. Both ships are owned and operated by the Second Port and Harbor Construction Bureau, Ministry of Transport. (Sokai literally means "blue Sea" and "Cleaning Sea.") Both ships are now engaged in routine recovery operation of thin films of oil which float on the sea surface. Figures 2 and 3 show a photograph of SOKAI and the general arrangement plan of NO. 2 SOKAI, respectively.

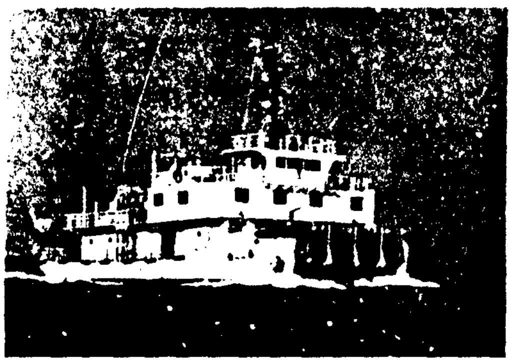

Figure 2. Oil recovery ship SOKAI

System Operation

By a combination of the floating regulating weir which allows the surface oily water to flow into the separating tank, aeration by small air bubbles in the separating tank, and vacuum suction, the system separates oil from the

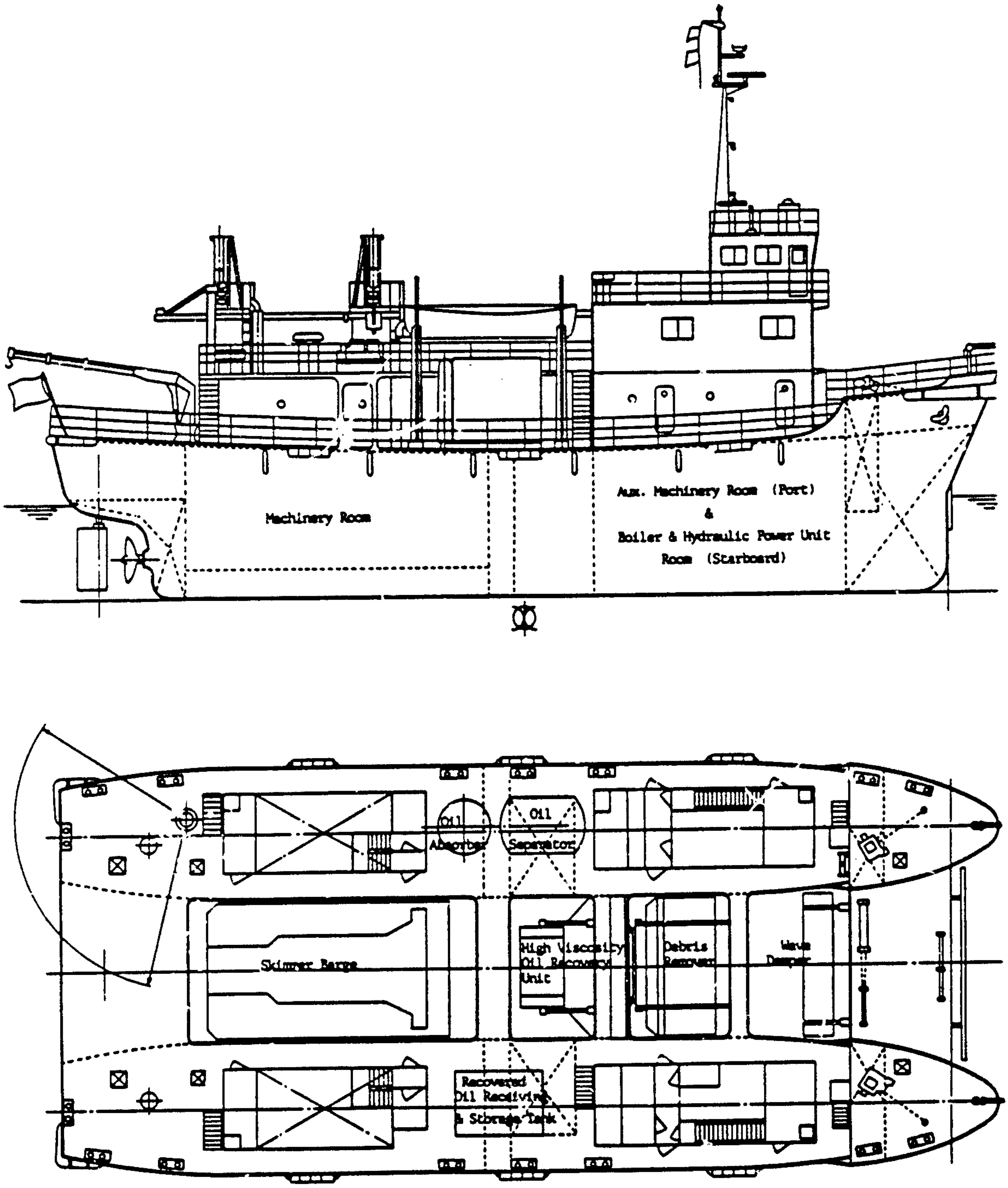

Figure 3. General arrangement plan of NO. 2 SOKAI

water and recovers the oil. A recovery schematic is shown by Figure 4. The actual operation of this recovery is as follows:

a. The oil recovery device ("skimmer barge") is moved into operating position.

b. The air compressor begins to pump air through pipes arranged throughout the first separating tank.

c. While the ship moves forward at low speed, the seawater discharge pump begins to discharge the water in the lower parts of the first and second separating tanks. When the water levels in the two tanks become low enough, the surface oily water in front of the ship flows into the first separating tank.

d. The oily water is aerated in the first tank where the oil adheres to the small air bubbles and floats to the surface underneath the oil separating plate. From the plate the oil flows into the second separating tank over the second flow regulating weir.

e. The vacuum pump suctions the separated oil through the floating oil-water suction equipment connected to the vacuum suction tank.

f. The suctioned oil is temporarily stored in the vacuum suction tank until it is eventually transferred to the large capacity oil storage tank. If the percentage of water is too high in the oil-water mixture in the vacuum tank, the oil-water separating equipment may be used to reduce the water percentage before transferring the oil for storage. Figure 5 shows the general arrangement of the skimmer barge.

Operation of SOKAI and NO. 2 SOKAI for Oil Spill Recovery

Tokyo Bay, where SOKAI and NO. 2 SOKAI operate, is surrounded by highly populated cities, including three cities with a million people: Tokyo, Yokohama, and Kawasaki. The total population of the bay area exceeds 20 million. The Tokyo Bay area also forms a large industrial complex composed of steel mills, chemical refineries, shipbuilding, electronic industries, etc. Since a huge amount of cargo to and from this area is transported by ships, Tokyo Bay is vital to the economy of the area. The total number of ships going into or out of the Bay is frequently as high as 750 per day. In addition, ferries, barges, work vessels, and fishing boats operate within the Bay. Naturally, traffic in the navigation channels is heavily congested and a high probability of accidents exists. Scattered in the bay area are thirteen oil refineries and five sea berths. Out of 750 ships navigating through the channel at the entrance of the bay on a given day, 150 are oil tankers. Under such heavily congested conditions, collisions between ships or grounding of ships is not uncommon and a considerable number of oil spills are reported every year. Both SOKAI and NO. 2 SOKAI have been dispatched to clean up such oil spills since their commissioning.

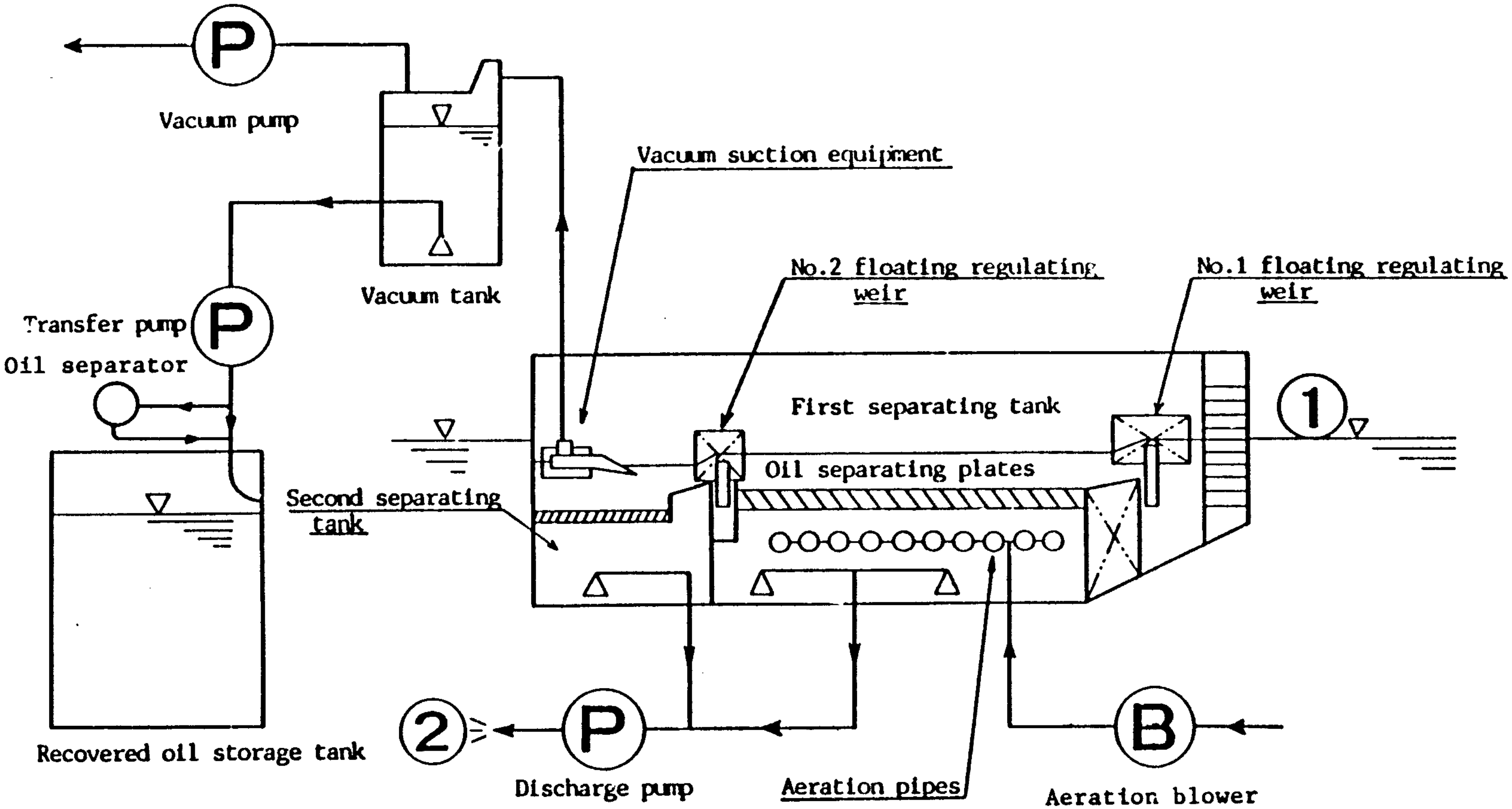

Figure 4. Schematic of aeration system

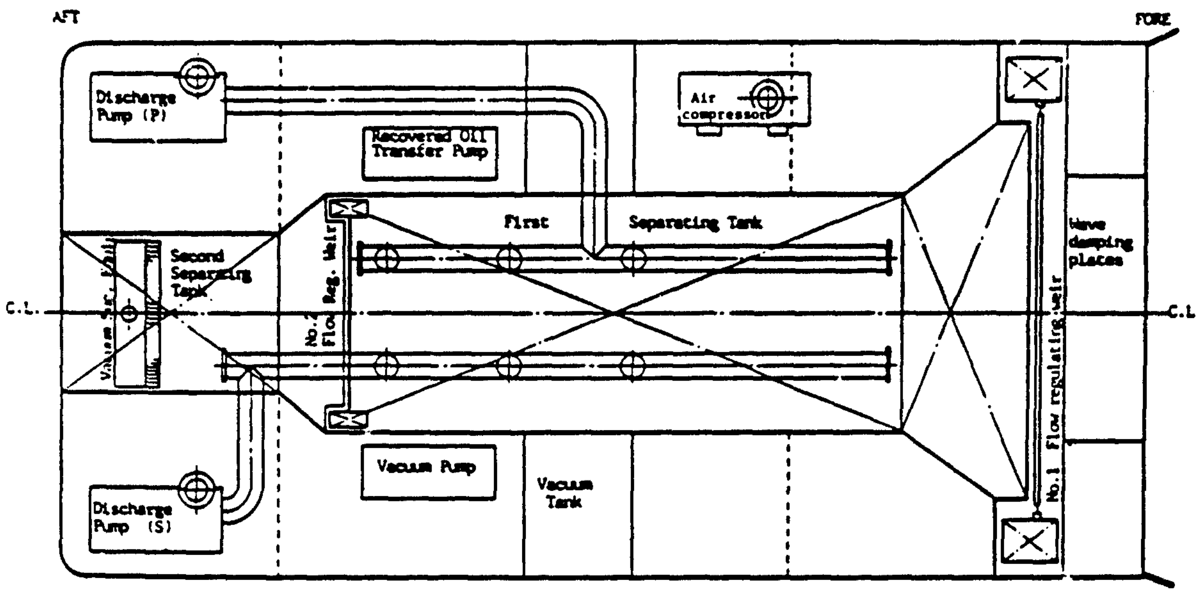

Figure 5. General arrangement of the skimmer barge

Table 2 presents information about oil spill incidents in which either SOKAI or NO. 2 SOKAI was dispatched upon request of the Maritime Safety Office of Tokyo Bay (3). Figures 6-8 are photos taken during those operations.

Unique Features

The two unique features of the aeration system are:

a. The system is suitable for recovery of relatively low viscosity oil which is found almost daily on the sea surface as "rainbow" film. The range of viscosity for effective recovery is from 1 to approximately 3,000 cSt.

b. As the oil is separated from the water by the action of numerous tiny air bubbles and suctioned by vacuum pressure into the oil separating tank, no additional materials, such as oil mat or chemical agents, are required. The system itself can recover low-viscosity oil which cannot be caught by an oil mat.

Recovery System for High Viscosity Oil

A recovery system for high viscosity oils, such as emulsified oil or solidified oil balls, was developed by the Second Port and Harbor Construction Bureau, Ministry of Transport, Japan, and IHI and fitted on SOKAI and NO. 2 SOKAI. This system is called the rotary bucket oil recovery system.

TABLE 2. SOME OIL SPILL INCIDENTS FOR WHICH SOKAI AND/OR NO. 2 SOKAI WERE DISPATCHED

Date	Source of Oil Spill	Amount and Type of Oil Spilled (Qty. or Size of Oil Belt	Cause of Spill	Oil Recovery Operation: Recovery Ship	Days Engaged	Oil & Water Recovered	Remarks
11-08-75	Unknown	4 km × 20-30 m C heavy	Unknown	SOKAI	1	22 m^3	
04-01-76	Lumber carrier	Not available	Unknown	SOKAI	2	115 m^3	
11-30-76	Cargo ship	20 kl (5,200 gal)	Collision	SOKAI	0	0	Prepared for operation, but cancelled
02-04-79	Land storage tank	50 kl, C heavy (13,000 gal)	Bottom breakdown	SOKAI	1	0	Prepared for operation, but cancelled
03-08-79	Oil supply ship	500 l, C heavy (130 gal)	Misoperation	SOKAI	1	38 m^3	Oil 1-1.5%
04-03-79	Car ferry	2 km × 50-100 m C heavy	Unknown	SOKAI & No. 2 SOKAI	1	0	
04-05-79	Land storage tank	200 kl, crude (52,000 gal)	Crack in tank plate	SOKAI & No. 2 SOKAI	1	43 m^3	
04-25-79	Container ship	1000 m × 70 m	Misoperation	SOKAI & No. 2 SOKAI		80 m^3	Oil 1-1.5%
09-13-79	Oil tanker Chemical tanker	4 kl, A heavy (1,040 gal)	Collision	SOKAI	2	100 m^3	Oil 0.1-0.5%
01-19-80	Tug boat Oil tanker	500 l, A, (130 gal) B heavy	Collison	No. 2 SOKAI	0.5	0	
01-19-80	Oil supply ship	165 l, C heavy (43 gal)	Misoperation	No. 2 SOKAI	0.5	33 m^3	Oil 0.5%
02-06-80	Cargo ship	N/A	Misoperation	No. 2 SOKAI	2	10 m^3	Oil 0.5%
12-07-81	Sand barge	1000 m × 500 m	Capsize	SOKAI & No. 2 SOKAI	1	60 m^3	Oil 0.5%
03-22-82	Coal carrier	600 kl (156,000 gal)	Grounding	SOKAI & No. 2 SOKAI	0	0	Standby

Figure 6. Oil spilled on the sea surface

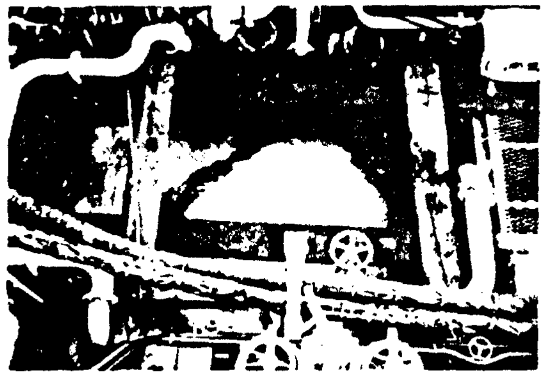

Figure 7. Aeration in the first separating tank during operation

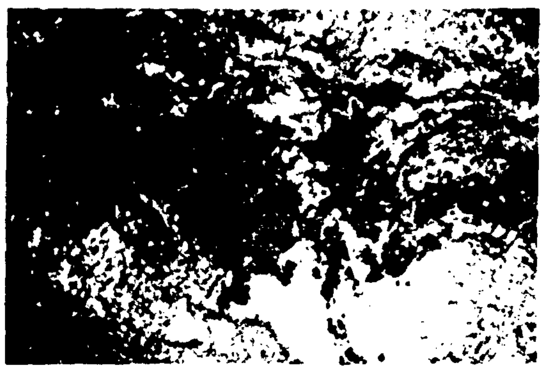

Figure 8. Oil separated by aeration

In 1974, the breakdown of a large storage tank in an oil refinery released a huge amount of heavy oil onto Seto Inland Sea of Japan. The released oil remained on the sea for months, became emulsified, and created conditions which made recovery of the high viscosity oil very difficult. All sorts of then-known methods of recovery were mobilized, but, unexpectedly, one of the most effective methods was the use of very primitive fishing tools--pails and wire net (see Figure 9).

Figure 9. Fisherman recovering spilled crude oil using hand nets and pails

Using this concept, a mechanical system which replaces the manual labor of fishermen was developed and named rotary bucket oil recovery system. The principles of the system are described below.

As shown in Figure 10, buckets with bottoms of wire net are fixed around an axle which is rotated by a hydraulically driven motor and belt. By the rotary action of the bucket axle, the oil on the water surface is moved forward and concentrated in front of the baffle plate where it is skimmed up by the bucket which releases the accompanying water through the wire net. Skimmed oil is automatically scraped off into the receiving trough and transferred by the screw conveyor to the oil suction mouths at both ends of the conveyor and pumped into storage tanks through fixed pipings. This operation is repeated continuously with the rotation of the bucket axle. The wire net is interchangeable and the appropriate mesh size is selected for each oil spill recovery mission. The whole unit is replaceable so that other types of recovery units can be used. Replacement of the unit is accomplished almost as easily as changing a cassette in a video recorder.

System Performance

Table 3 shows the results of a recovery test conducted in a test basin with smooth water. Test conditions are listed below:

a. Thickness. Thickness of the oil layer on the water surface was approximately 70 mm for B heavy oil and approximately 100 mm for C heavy oil.

b. Time. The time of the test was January, when temperature was very low. Oil was emulsified to ensure high viscosity. Emulsification was accomplished by means of pumps which circulated the oil sufficiently to accomplish this purpose.

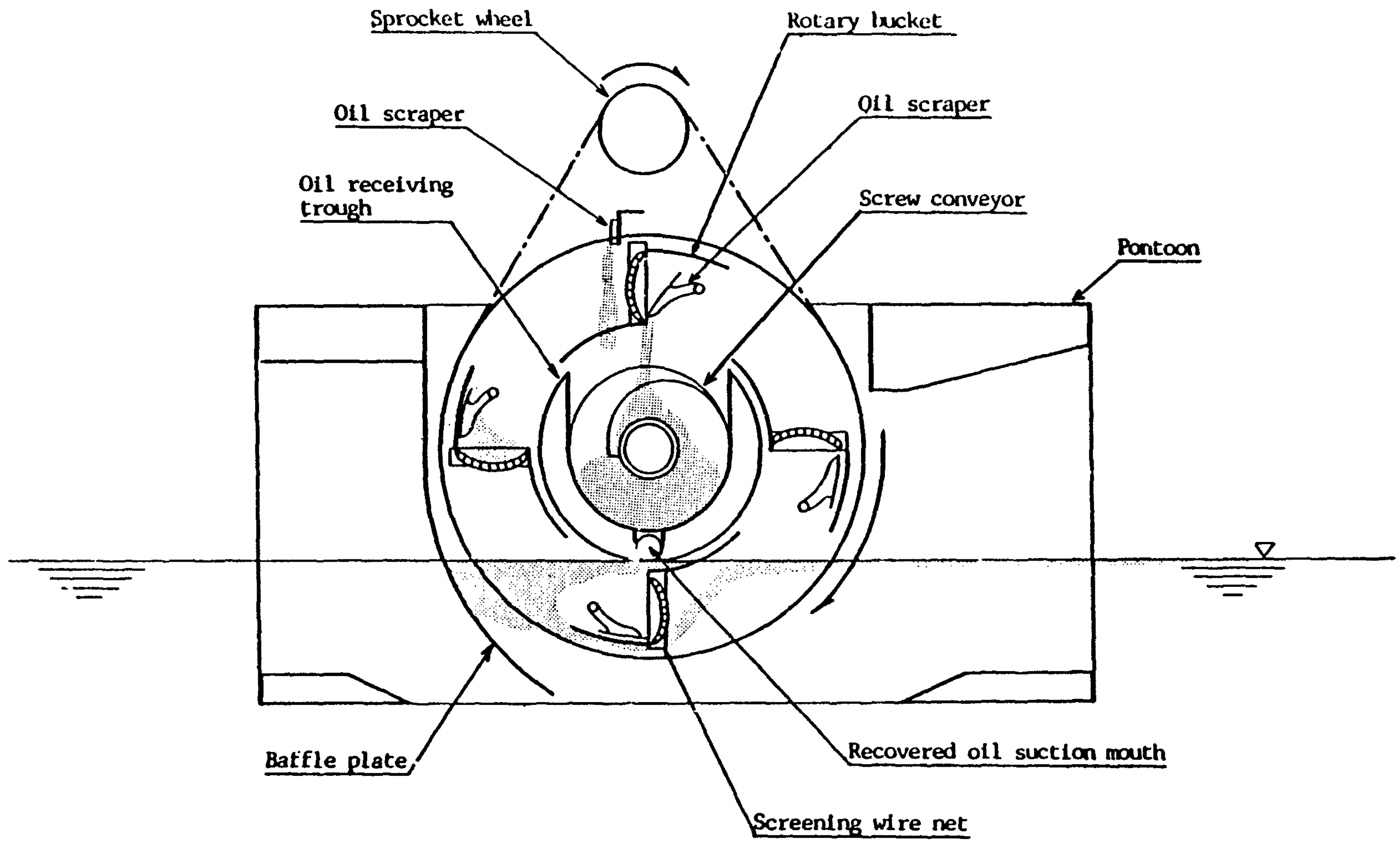

Figure 10. Rotary bucket oil recovery system

TABLE 3. PERFORMANCE OF ROTARY BUCKET OIL RECOVERY SYSTEM

Oil Used	Viscosity* cP	Wheel Revolutions rpm	Oil & Water m^3/hr	Oil m^3/hr	Water Concentration %	Mesh Size of Wire Net
B heavy	6,000	10.0	30	21.0	30	7
B heavy	50,000	5.0	30	26.7	11	7
B heavy	50,000	15.0	25	13.2	56	2
C heavy	150,000	3.5	30	28.2	6	2
C heavy	450,000	5.5	30	25.5	15	2
C heavy	1,000,000	6.5	30	22.5	25	2
C heavy	1,400,000	7.0	30	21.0	30	2
C heavy	700,000	6.0	30	18.0	40	4
C heavy	1,000,000	5.5	30	15.0	50	7

* cP: Centipoise: 1/100 of poise, nearly equal to cst (centistokes).

c. Water concentration. Data in Table 3 were measured by weight ratio of water separated by gravity settling versus total weight of oil and water recovered, exclusive of water caught by emulsified oil, i.e., the apparent water concentration.

Test results are listed below:

a. It was proved that the system was widely adaptable to different viscosities of oil from some thousands of cP's up to one million cP and higher by selecting appropriate mesh of wire net and different oil viscosity conditions.

b. There is an optimum mesh size of wire net for each oil viscosity condition.

c. Oil with a viscosity greater than 500,000 cP could be transferred with no problem due to the lubricating action of a water film on the inside of pipes. Figure 11 shows viscous oil greater than 500,000 cP being discharged from a transfer hose.

Unique Features

The system is capable of recovering oil with a range of viscosity from 5,000 cP to 1,500,000 cP, which cannot be recovered by other methods such as direct suction by pumping, adhesion recovery system, or oil absorption mat.

Compared with the gelatinization method which uses chemical agents (discussed below), the operating cost of the bucket system is much lower.

Figure 11. High viscosity oil being discharged

Gelatinization Oil Recovery System

Another method of recovery for relatively small oil spills in harbors is gelatinization by a chemical agent which solidifies on contact with water and forms a "mousse" together with the oil. The mousse can be recovered easily by wire net or other similar devices. This system has been studied by the Japan Association for Preventing Marine Accidents and has been applied to a sea-surface cleaning ship built in Japan (Figures 12 and 13). Chemical characteristics of the gelatinization agent are listed in Table 4 (4).

Figure 12. Sea-surface cleaning ship with gelatinization oil recovery system

Application

Between the two hulls of a sea-surface cleaning catamaran, a rotor with disks is positioned above the water surface so that the lower part of each disk is immersed. Near the bow, ahead of the rotor, nozzles for spreading gelatinization agent are positioned over the water surface by pumping. When the ship is moving at 1.0 to 1.5 knots, the oil on the sea surface flows into

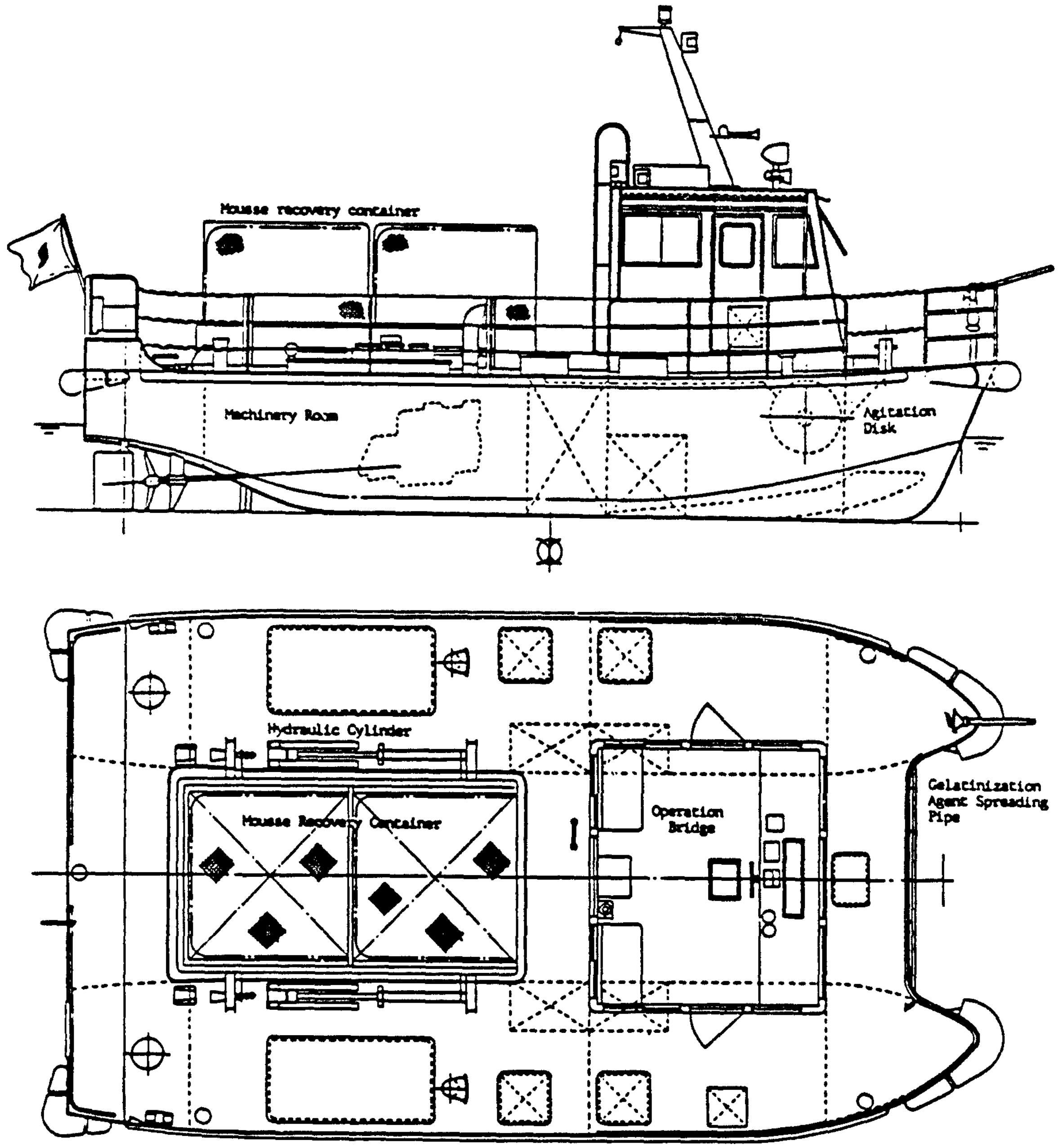

Figure 13. General arrangement of sea-surface cleaning ship with gelatinization oil recovery system

TABLE 4. PHYSICAL PROPERTIES OF GELATINIZATION AGENT

Item	Description
Appearance	Pale yellow liquid
Main ingredients	Amino acid derivative; content: 9%
Specific gravity	0.8 (30°C), 0.87 (10°C)
Viscosity	16 cst (30°C), 27 cst (10°C)
Flash point	82°C (open)
Freezing point	Below 0°C

the well between the two hulls. Near the bow the gelatinization agent is spread over the in-flowing oil and water. When the mixture passes through the rotor with disks, the oil, water, and chemical agent are stirred to form gelatinized mousse which is caught in the recovery container by a textile net. The solidified oil in the mousse is recovered for delivery to the land processing facility by lifting up the container. The container amount of gelatinization agent for this purpose is about 30 percent of agent per unit of spilled oil by weight.

Recovery Examples

To date, many incidents of oil recovery by gelatinization have been reported. The following are two noteworthy examples:

a. In October 1979, a Chinese 8000 DWT cargo ship grounded off Erimo Cape, Hokkaido, northern island of Japan. This resulted in a spill of 14 tons of A and C heavy oil in the flooding engine room. A gelatinization agent was spread over the surface of the oil spill by portable pumps. The entire amount of spilled oil was recovered in the form of gelatinized mousse in hand nets in 10 days.

b. The grounding of a 3000 DWT lumber carrier off Rumoi, Hokkaido, in January 1980 caused an oil spill (C heavy oil) on the sea surface. While the spilled oil was held within an oil fence, a gelatinization agent was spread from a small boat and the 6.4 tons of spilled oil was recovered in 9 days.

Outstanding Features

After oils, including crude and heavy oils, spill on the sea, their nature changes as time lapses. Certain oils remain liquid, but others become solidified into a semisolid "mousse." To date, no single mechanical system can recover all such states of oil.

The gelatinization agent solidifies all types of oil into a form which can be easily recovered like other floating debris by a mechanical method. In other words, the most unique feature of the gelatinization method is that it can recover all sorts of oil, which no other single oil spill recovery method can accomplish.

Figures 14 and 15 show gelatinized C heavy oil on the water surface and recovered mousse, respectively. Gelatinized diesel oil recovered by a hand net is shown in Figure 16.

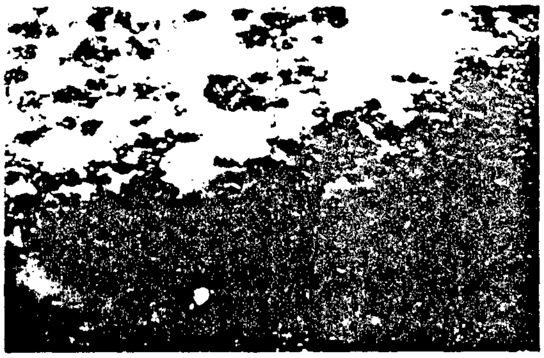

Figure 14. Gelatinized C heavy oil

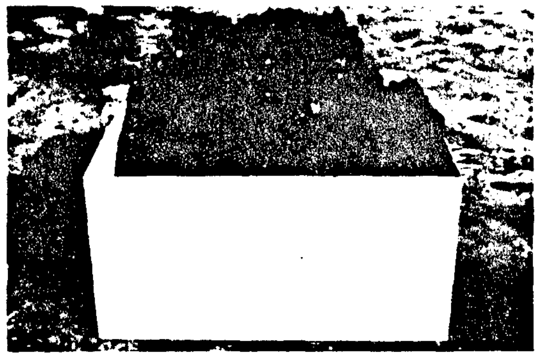

Figure 15. Recovered mousse

Figure 16. Recovery of mousse by a hand net

The effect of the gelatinization agent on marine life was examined by the Water Pollution Prevention Committee of the Japan Marine Accidents Prevention Association and the results showed little adverse effects on fish, shellfish, plankton, seaweed, etc. The use of a gelatinization agent causes no harm to such marine life.

According to the safety code stipulated by the Ministry of Transport, the concentration of other oil processing chemicals allowed in the water in terms of toxicity against fish is 3,000 ppm while the concentration of gelatinization agent giving the equivalent toxicity is 42,000 ppm. This indicates that the agent is safe for marine life.

The solidified mousse does not emit any flammable gas. This eliminates danger of fire which greatly eases recovery and processing work afterwards.

The gelatinized mousse is lighter than, and free of, water and is not adhesive, which ensures easy recovery by manual methods or mechanical devices. In addition, the gelatinized mousse remains solid below the temperature of

60°C and recovery efficiency does not decrease, even in summer. Storage and transportation of mousse are easily accomplished.

CONCLUSIONS

Three typical oil recovery systems currently used in Japan include:

a. A recovery system for low viscosity oil which spreads itself over the water surface as a thin film layer.

b. A recovery system for high viscosity oil, like crude or heavy oil, which remains on the water surface in a thick layer.

c. A gelatinization recovery system which solidifies all types of oil into a mousselike material for easy mechanical recovery.

In spite of the many oil spills which occur on a worldwide or even a regional basis, there are not usually enough spills in a given local area to make it cost-effective to maintain single purpose oil spill recovery ships. It would be more economical to have ships, such as tugboats or dredges, which can perform other missions besides oil spill recovery. As a matter of fact, some such ships have already been built.

The ships with the gelatinization oil recovery system introduced in this paper are normally used for recovery of floating refuse in harbors, and can be dispatched as oil recovery ships upon the occurrence of oil spills.

The authors will be pleased if such oil recovery systems should contribute to maintaining the world's irreplaceable and beautiful sea environment.

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THEORETICAL CONSIDERATION OF POND AND SPILLWATER TREATMENT DESIGN

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ABSTRACT

In the treatment of dredged material, we must determine the necessary factors for pond design or spillwater treatment design. To do this, laboratory tests must be performed. If the test results are evaluated correctly, there is no problem. However, it is not always easy to evaluate them theoretically.

For example, the mean settling velocity of solid particles is usually obtained as the angle of the tangent line to the descending curve of the clarified liquid boundary. Strictly speaking, this is not correct. This paper deals with such problems.

SEDIMENTATION TEST

The treatment of dredged material is based on the separation of solids and liquids. The separation of a solid from a liquid is usually achieved via a settling pond. The size of a settling pond depends principally upon the mean settling velocity of the sediment particles concerned.

To learn this, a sedimentation test is performed using an acrylic pipe which usually has a diameter of 200 mm and a length of 1500 to 2000 mm (Figure 1).

In this test, the boundary between clarified (liquid) and suspended solids (SS) containing liquids, which descends with time, is measured by heights according to time. Figure 2 shows an example of the test results.

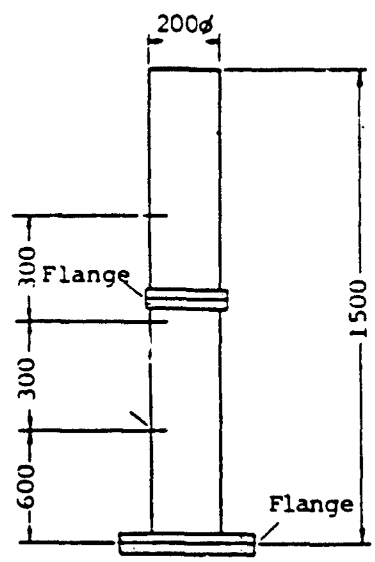


Figure 1. Sedimentation test apparatus

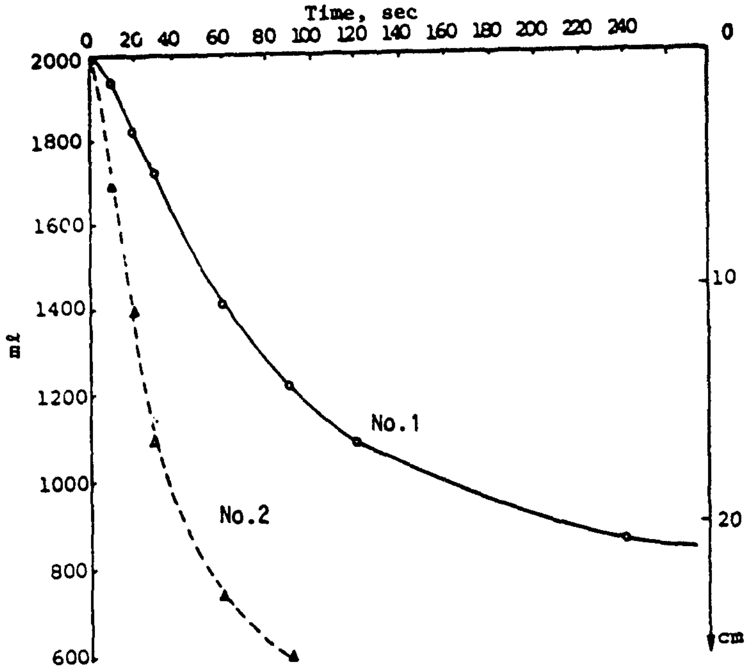
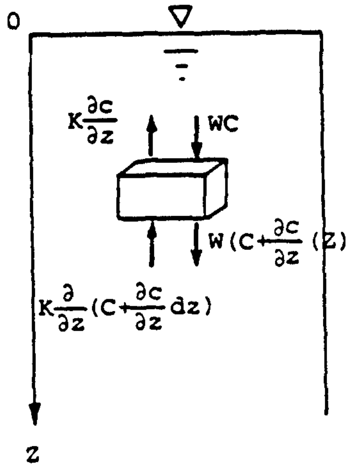


Figure 2. Precipitation curve

In Figure 2, two precipitation curves which have initial concentrations of 19,420 mg/ℓ (No. 1) and 14,860 mg/ℓ (No. 2) are plotted. The movement of solid particles in a test pipe is represented as follows:



$$\frac{\partial c}{\partial t} = -W \frac{\partial c}{\partial z} + K \frac{\partial^2 c}{\partial z^2} \tag{1}$$

where

Z = Water depth

t = Time

c = Concentration of SS

w = Mean settling velocity of floc

K = Diffusion coefficient of floc in the vertical direction

As the solution of Equation 1 we have the following equation, using a boundary condition $t = 0$, $z = \frac{H}{2}$, and $C = C_o$:

$$C = C_o e^{-n^2 t} e^{\frac{W}{2K}\left(z - \frac{H}{2}\right)} \frac{\cos \frac{bw}{2K} z - \frac{3}{b} \sin \frac{bw}{2K} z}{\cos \frac{bw}{2K} \frac{H}{2} - \frac{3}{b} \text{ in } \frac{bw}{2K} \frac{H}{2}} \tag{2}$$

$$b = \sqrt{\frac{4Kn^2}{W^2} - 1}$$

where

C = SS concentration

C_o = Initial SS concentration of dredged material

H = Initial liquid height

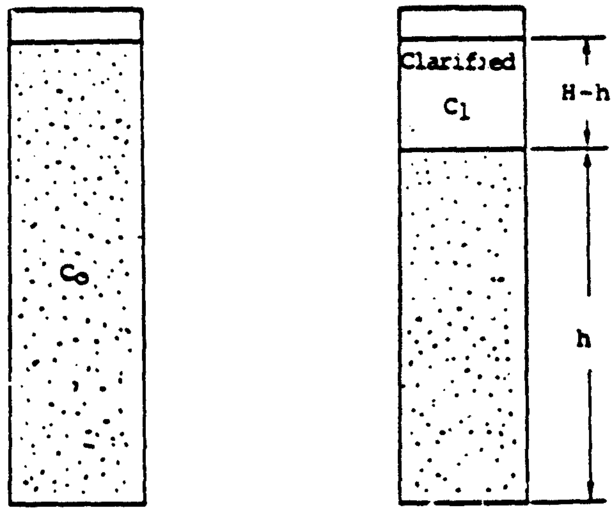
Here putting,

$$\alpha(z) = \frac{\cos \frac{bw}{2K} z - \frac{3}{b} \sin \frac{bw}{2K} z}{\cos \frac{bw}{2K} \frac{H}{2} - \frac{3}{b} \sin \frac{bw}{2K} \frac{H}{2}} \tag{3}$$

We rewrite Equation 2 in the following form:

$$C = C_o e^{-n^2 t} e^{\frac{w}{2K}\left(z - \frac{H}{2}\right)} \alpha(Z) \tag{4}$$

Since the variation of SS concentrations against t and z is now known, we can calculate the concentration of clarified liquid:



t = o   after t

$$\bar{C} = \frac{1}{H-h}\int_{o}^{H-h} C_o e^{-n^2 t} e^{\frac{w}{2K}\left(z - \frac{H}{z}\right)} \alpha(z)\,dz$$

$$= \frac{C_o e^{-n^2 t}\,\frac{2K}{w}\,e^{-\frac{w}{2K}\frac{H}{2}}\;\Big| e^{\frac{w}{2K}(H-h)}\left[4\cos\frac{bw}{2K}(H-h) + \frac{b^2-3}{b}\sin\frac{bw}{2K}(H-h)\right] - 4}{(H-h)(1+b^2)\left(\cos\frac{bw}{2K}\frac{H}{2} - \frac{3}{b}\sin\frac{bw}{2K}\frac{H}{2}\right)} \tag{5}$$

Here we set two nondimensional symbols as follows:

$$\beta = f\left(\frac{bw}{2K},\ b,\ H\right)$$

$$= \frac{e^{-\frac{w}{2K}\frac{H}{2}}}{(1+b^2)\left(\cos\frac{bw}{2K}\frac{H}{2} - \frac{3}{b}\sin\frac{bw}{2K}\frac{H}{2}\right)} \tag{6}$$

$$\gamma = f\left(\frac{bw}{2K},\ \frac{w}{2K},\ b,\ H-h\right)$$

$$= e^{\frac{w}{2K}(H-h)}\left[4\cos\frac{bw}{2K}(H-h) + \frac{b^2-3}{b}\sin\frac{bw}{2K}(H-h)\right] - 4 \tag{7}$$

Hence we have

$$\bar{C}_1 = C_o e^{-n^2 t} \frac{2K}{w} \beta \frac{\gamma}{H - h} \tag{8}$$

or

$$F(H - h) = \frac{H - h}{\gamma} = \frac{C_o}{\bar{C}_1} \frac{2K}{w} e^{-n^2 t} \tag{9}$$

This is an equation for the descending clarified liquid surface.

As Equation 9 shows, the descending height of liquid surface is represented by a function of $\frac{H - h}{\gamma}$, which is not a single function such as an exponential one.

One should note that Equation 9 is not complete for the whole settling procedure because in the latter half zone settling and consolidation of solids occur. Therefore, some difference between the curve of Equation 8 (Figure 3) and an observed curve is inevitable.

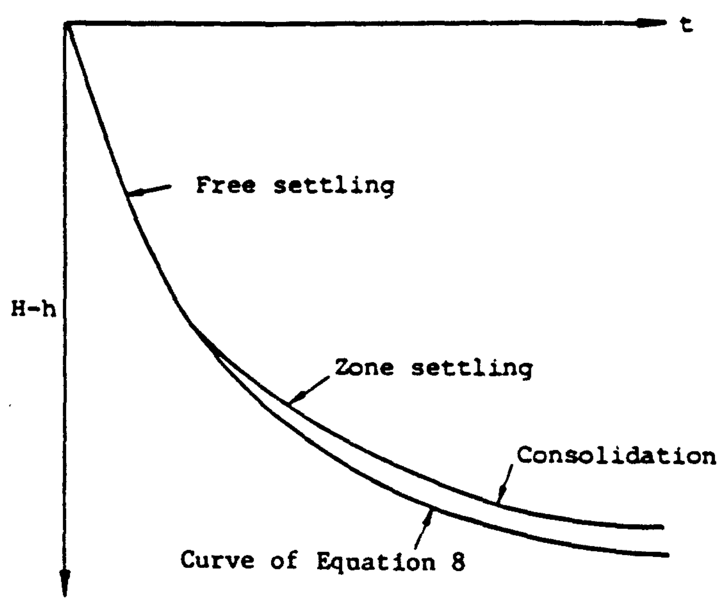


Figure 3. Curve of Equation 8

SETTLING VELOCITY

The main purpose of a settling test is to obtain the mean settling velocity (Figure 4).

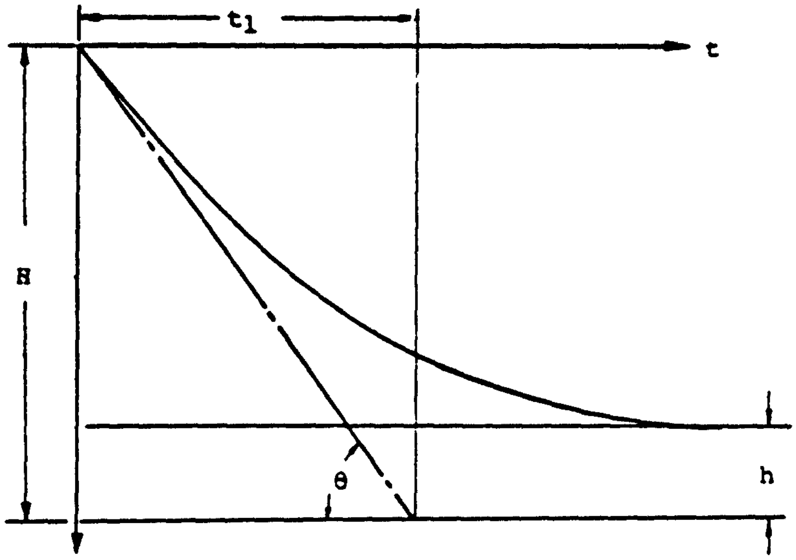


Figure 4. Determination of settling velocity

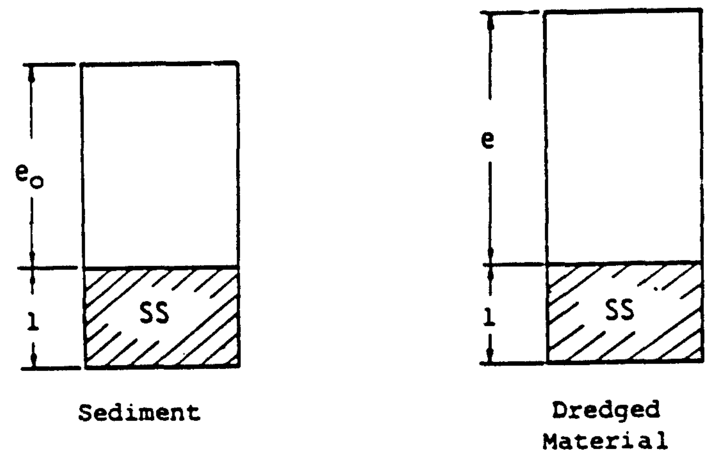
The mean settling velocity is usually obtained from a tangential line at some early time for brevity of calculation. But this is not correct. The descending rate of clarified liquid surface is represented as follows from Equation 9:

$$\frac{F(H - h)}{dt} = \frac{C_o}{C_1} \cdot \frac{2K}{w} (-n^2)e^{-n^2 t} \tag{10}$$

As the equation shows, the angle of a tangent line is a complicated function of n^2 , b , w , and K . It does not represent the settling velocity. The factor which strongly affects the slope is the value of n^2 . The reason lies in the fact that the descent of the clarified liquid boundary is caused not only by the settling of solid, but also by the diffusion of solids particles. If we want to know the true settling velocity, we must compute Equations 4 and 8 with measured data.

SWELLING OF DREDGED MATERIAL

Sediment at the water bottom has a void ratio (e_o) in its natural state. When it is dredged, the sediment particles are disturbed by the dredge cutter and become loose. Therefore, the dredged material has a larger void ratio than that of the sediment. Consequently, when we place it into settling ponds, we must account for this swelling of the dredged material.



The swelling of the dredged material is represented as follows:

$$\varepsilon = \frac{1 + e}{1 + e_o} \tag{11}$$

From a settling test, we can obtain the void ratio of dredged material by the following equation:

$$e = \frac{\gamma_s}{C_o} \frac{h}{H} - 1 \tag{12}$$

where

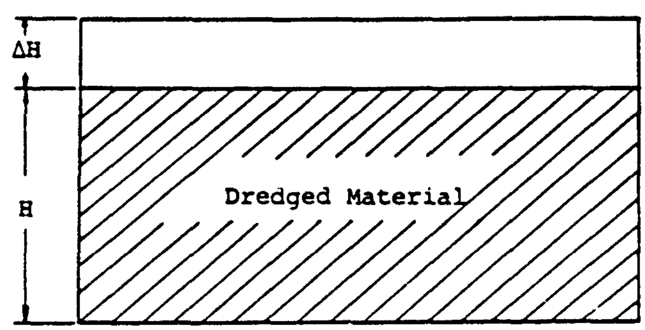
C_o = Initial SS concentration of dredged material

γ_s = Specific weight of dredged material

h = Settled thickness of solid

H = Initial liquid height

As to the value of e_o, we must measure it beforehand.



When designing a settling pond, the capacity should be determined by the following equation:

$$V = V_o \varepsilon \left(1 - \frac{\Delta H}{H}\right) \tag{13}$$

where

V = Pond capacity

V_o = Sediment quantity to be dredged

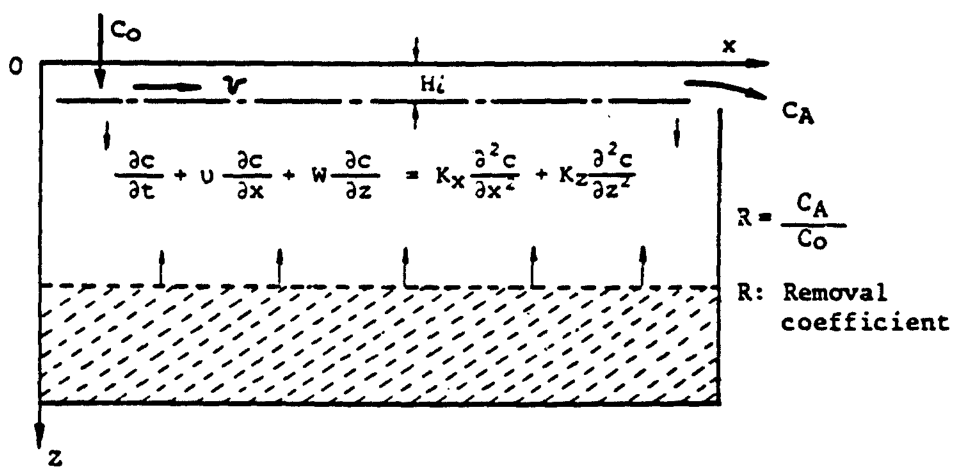
ε = Swelling ratio

ΔH = Settlement of dredged material

REMOVAL COEFFICIENT OF SS

In a settling pond dredged material is separated into solid and liquid components. The former settles in the pond and the latter flows over a spillway.

In most cases, the quality of the spill water is not very clean from such sedimentation. Therefore, spill water treatment is necessary. In this case, it is most important to predict the spill water quality because it is basic to treatment design.



The movement of solid particles in a pond is represented by the following equation:

$$\frac{\partial c}{\partial t} + \upsilon \frac{\partial c}{\partial x} + W \frac{\partial c}{\partial z} = K_x \frac{\partial^2 c}{\partial x^2} + K_z \frac{\partial^2 c}{\partial z^2} \tag{14}$$

where

C = SS concentration

υ = Flow velocity in pond surface

W = Mean settling velocity of solid particle

K_x = Diffusion coefficient in the horizontal direction

K_z = Diffusion coefficient in the vertical direction

From the exact solution of Equation 15, we can obtain the SS concentration of spill water as follows:

$$C_A = C_o \sum_{n=1}^{\infty} \frac{16b^2\lambda^2{}_n\sqrt{\lambda^2{}_n + 1}\; e^{a\ell+bh-\sqrt{\lambda^2{}_n+1}\cdot\ell}}{h(\lambda^2{}_n + b^2)^2\left[(\lambda^2{}_n + b^2)h + 2b\right]\left(\sqrt{\lambda^2{}_n + 1} + a\right)}$$

$$a = \frac{\upsilon}{K_x}\sqrt{\frac{K_x}{\upsilon^2/K_x + tw^2/K_z}}$$

$$b = \frac{w}{K_z}\sqrt{\frac{K_z}{\upsilon^2/K_x + w^2/K_z}} \qquad (15)$$

$$h = \frac{\Delta H}{2}\sqrt{\frac{\upsilon^2/K_x + w^2/K_z}{K_z}}$$

$$\ell = \frac{L}{2}\sqrt{\frac{\upsilon^2/K_x + W^2/K_z}{K_x}}$$

$$\tan \lambda nh = \frac{2\lambda_n b}{\lambda^2{}_n - b^2}$$

In this case, it is convenient to include the concept of a removal coefficient as $R = C_A/C_o$. This coefficient depends upon sediment properties and pond conditions. Figure 5 shows some relationships between R and settling velocity W. Figure 6 shows some relationships between R and pond length.

In the treatment of dredged material, the required value of R is set in each case. Roughly speaking, a reasonable value in a settling pond is about 2×10^{-3}. If the required value of the project is expected to be more than this value, spill water treatment becomes necessary.

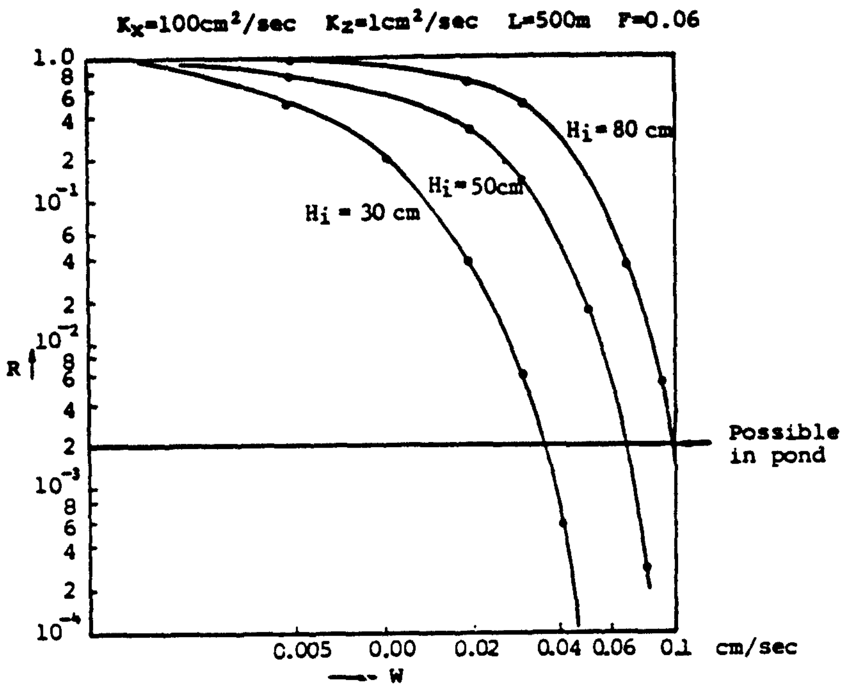


Figure 5. Relationship between R and settling velocity W

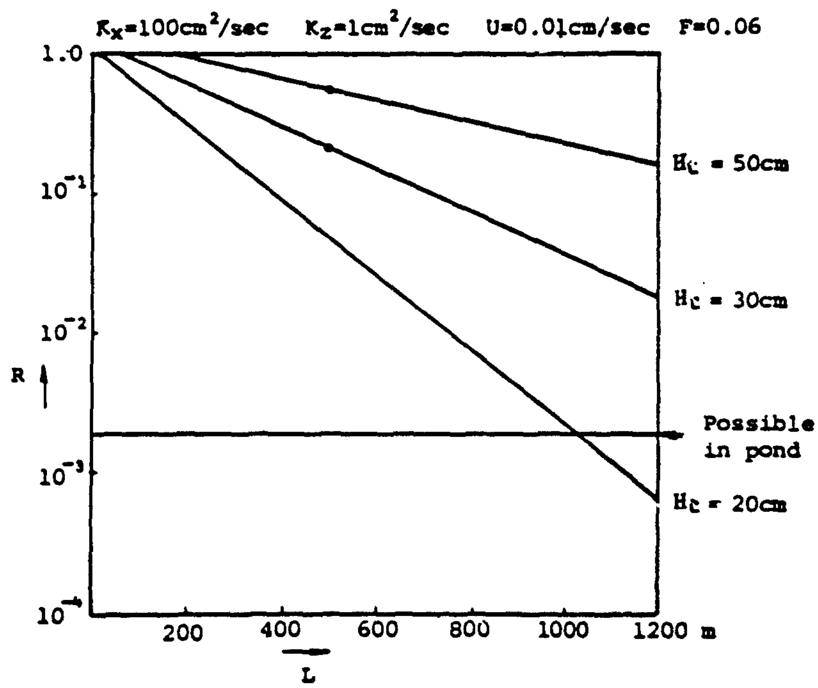
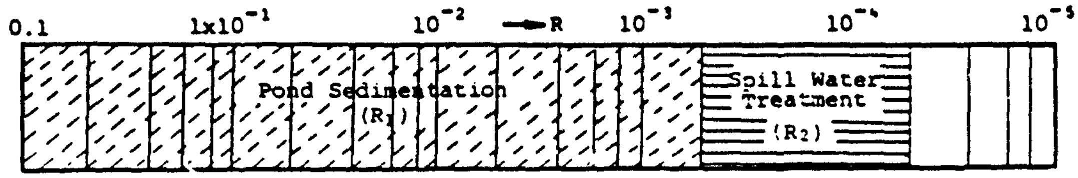


Figure 6. Relationship between R and basin length L



$$R = \underset{\substack{\uparrow \\ \text{Pond}}}{R_1} \times \underset{\substack{\uparrow \\ \text{Spill Water Treatment}}}{R_2}$$

REMOVAL OF POLLUTANTS

It is clear that the removal of suspended solids aids the removal of pollutants. The efficiency of pollutant removal depends upon the interposing conditions between solid particles. According to our laboratory tests, the relationships between the removal efficiencies of SS and pollutants are:

i) PCB

$$R_{SS} = \frac{20 \text{ mg}/\ell}{20{,}000 \text{ mg}/\ell} = 1 \times 10^{-3}$$

$$R_{PCB} = \frac{7 \ \mu\text{g}/\ell}{4.8 \text{ mg}/\ell} = 1.5 \times 10^{-3}$$

(PCB concentration in sediment = 750 mg/kg, void ratio = 5, sediment content = 10%)

ii) Hg

$$R_{SS} = \frac{18 \text{ mg}/\ell}{20{,}000 \text{ mg}/\ell} = 0.9 \times 10^{-3}$$

$$R_{Hg} = \frac{7 \ \mu\text{g}/\ell}{1.78 \text{ mg}/\ell} = 3.9 \times 10^{-3}$$

(Hg concentration in sediment = 278 mg/kg, void ratio = 5, sediment content = 10%)

iii) Oily substances

$$R_{SS} = \frac{50.8 \text{ mg}/\ell}{46{,}450 \text{ mg}/\ell} = 1.1 \times 10^{-3}$$

$$R_{oil} = \frac{4.6 \text{ mg}/\ell}{243 \text{ mg}/\ell} = 1.9 \times 10^{-2}$$

(Oil concentration in sediment = 38,000 mg/kg, void ratio = 5, sediment content = 10%)

As Figure 7 shows, the removal efficiencies of SS for the three samples are nearly equal, showing the value of 1×10^{-3}. However, the removal efficiencies of pollutants are different, showing the values of 1.9×10^{-2} to 3.9×10^{-3}.

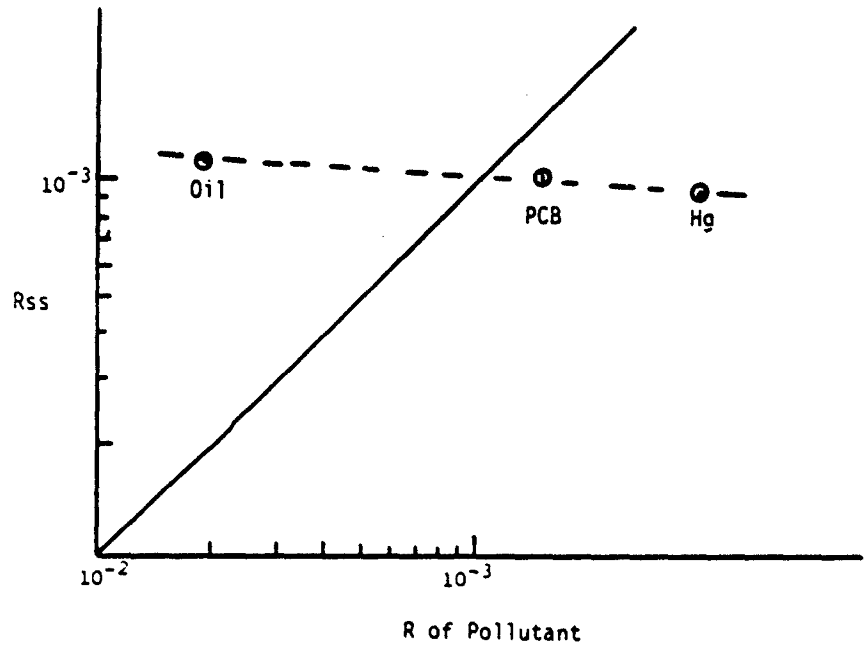


Figure 7. Relationships between removal efficiencies of SS and pollution

Here we take the ratio of R_{SS} to R of pollutants:

$$\text{PCB} = \frac{1.5 \times 10^{-3}}{1 \times 10^{-3}} = 1.5$$

$$\text{Hg} = \frac{3.9 \times 10^{-3}}{0.9 \times 10^{-3}} = 4.3$$

$$\text{Oil} = \frac{1.9 \times 10^{-2}}{1.1 \times 10^{-3}} = 0.17$$

The smaller the ratio, the larger the difficulty of removal of pollutants. From this point of view, the removal of oily substances is the most difficult. Among these pollutants, the reduction of mercury concentrations is the least difficult.

CONCLUSIONS

As mentioned, the settling tube test is the most popular method for planning settling ponds and spill water treatment. However, it seems that there is some doubt about the correct evaluation of test results. We believe that our theoretical analysis of this problem would be useful in making this correct evaluation.

ST. LAWRENCE SEAWAY PRECISE NAVIGATION

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BACKGROUND

The St. Lawrence Seaway (Figure 1) is the deep draft waterway which serves the North American mid-continent, allowing vessels to overcome the 600-ft elevation difference between Lake Superior and the Atlantic Ocean by means of a series of 16 locks and associated channel improvements. The Soo Locks and the St. Marys River channel, connecting Lakes Superior and Huron, are operated and maintained by the U. S. Army Corps of Engineers, which also maintains the other channels in the upper Great Lakes. The Welland Canal, which has 8 locks and parallels the Niagara River between Lakes Erie and Ontario, is operated and maintained by the St. Lawrence Seaway Authority of Canada. The area of specific concern for this paper is the St. Lawrence River portion of the system, which comprises the reach from Tibbetts Point, New York (on Lake Ontario), to Montreal, Quebec, and includes 7 locks--2 U. S. and 5 Canadian.

The Saint Lawrence Seaway Development Corporation (SLSDC) is one of the operating administrations of the U. S. Department of Transportation, and is a wholly owned U. S. Government Corporation, responsible for operating and maintaining the U. S. portion of the system. This is accomplished in close coordination and cooperation with our Canadian counterpart, the St. Lawrence Seaway Authority of Canada (SLSA). Authority for direct coordination is provided for in the enabling legislation of both entities. The SLSDC is responsible for navaids and channel maintenance in U. S. waters and for vessel traffic control in three sectors between Montreal and mid-Lake Ontario. Canadian navigation aids are provided by the Canadian Coast Guard, while the SLSA operates the rest of the system, including vessel traffic control in five of the eight sectors between mid-Lake Erie and Montreal. The Seaway entities also set and enforce vessel speed limits in the waterway for the protection of life and property.

The SLSDC is financed entirely by user charges, collected in the form of tolls on vessels and their cargoes. Seaway navaids in U. S. waters are thus currently financed directly from user charges, and it is reasonable to assume that any future improvements will be similarly funded.

St. Lawrence River commercial traffic is largely comprised of two types of vessels--the so-called "Laker" fleet, primarily Canadian bulk carries of maximum Seaway size, and the "Salties," that portion of the ocean fleet (about 75 percent) which is not constrained by the limiting lock dimensions (width and length). The maximum Seaway vessel is 76 ft in beam, 730 ft long, and has a maximum draft of 26 ft. In 1979, a total of 6,363 transits were made at Eisenhower Lock, comprised of 4,633 commercial transits, 439 noncargo

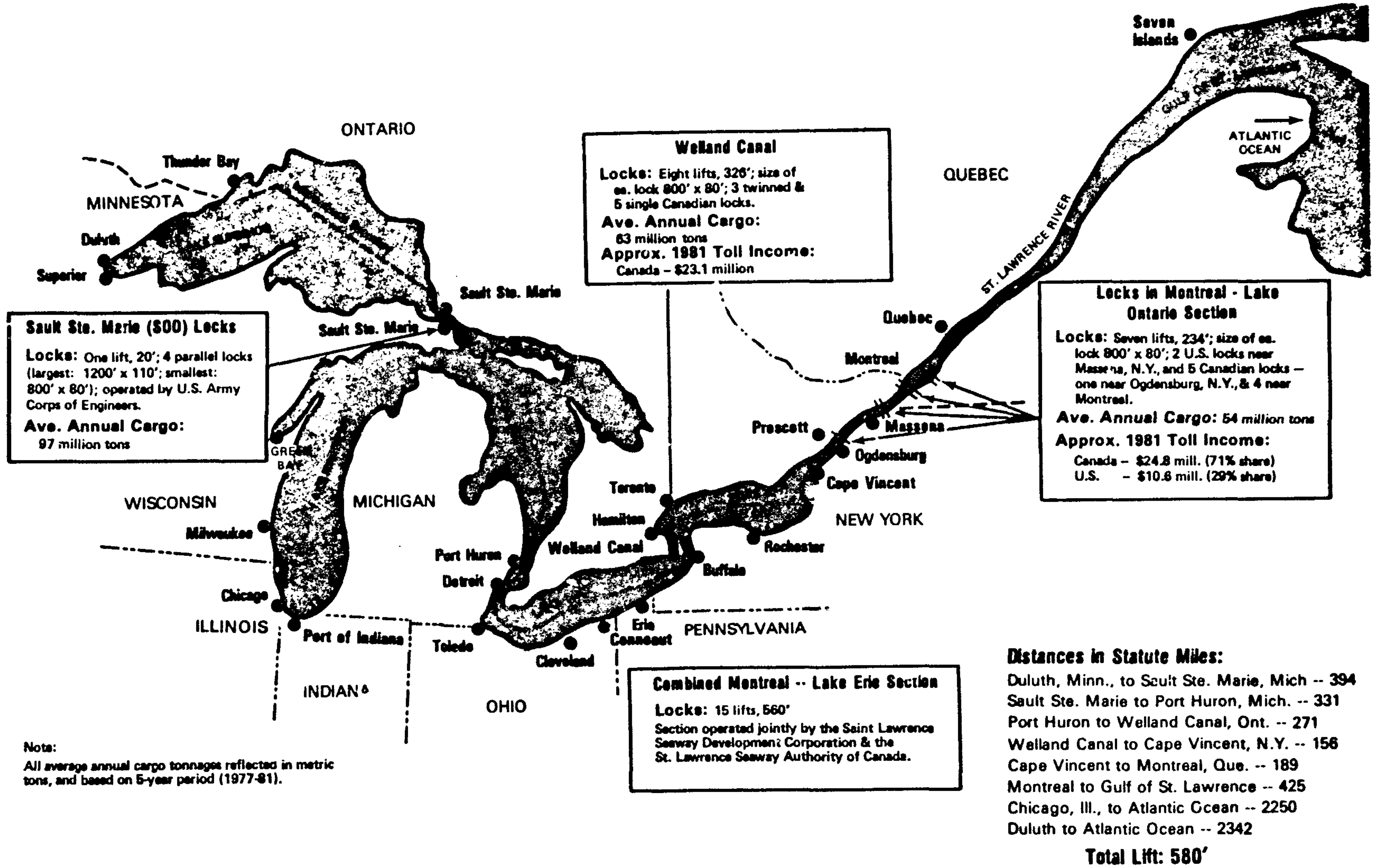

Figure 1. St. Lawrence Seaway System

transits, and 1,291 transits by pleasure craft. The commercial vessels moved some 55.3 metric tons of cargo through the St. Lawrence River in 1979.

The current navigation season runs from about 1 April to 20 December each year. The system is thus shut down due to weather and ice conditions for about 100 days each year.

THE SEAWAY NAVIGATION PROBLEM

Two measures of system performance are important to the operating entities and to the vessel operators. System capacity is the measure of the ability of the system to move cargo per unit of time and is usually expressed in transits per day or in tons per year. Capacity is normally constrained by the time required to process a vessel through the slowest lock. However, in times of low visibility or when floating, lighted navigation aids are not available in specific channel reaches, the capacity constraint shifts to those reaches. The second performance parameter is vessel transit time required for negotiation of the Montreal to Lake Ontario section of the Seaway. This translates directly into vessel operating costs.

At the beginning of each navigation season the commissioning of floating lighted aids is delayed up to 4 weeks due to ice in the River, which complicates settling buoys, and which may damage them or move them off station. Toward the end of the season the floating, lighted aids must usually be decommissioned before the close of navigation, again because of ice. There are also periods throughout the navigation season when visibility is too low for vessels to proceed safely with the available navigation aids. It is important to emphasize in this discussion that the Seaway entities are addressing a piloting system as opposed to a surveillance system, such as the system in operation on the Suez Canal, for example. The accuracy and reliability requirements for pilotage are much more stringent than for surveillance. In connection with the channel maintenance operation, accuracy requirements are even more stringent, but reliability is not as critical since safety is not involved.

There are 190 miles of channel between Montreal and Lake Ontario, with 87 course changes and 7 locks. In the 120 miles between Lake Ontario and the Quebec border, the International Boundary crosses the channel limits some 36 times before it finally leaves the River. Representative minimum widths between Montreal and Lake Ontario are:

180 ft through two bridge draws in the Beauharnois Canal
220 ft in the South Shore Canal
425 ft in the Brockville Narrows
442 ft in the Wiley-Dondero Canal
450 ft in portions of the American Narrows

Some 68 miles or 36 percent of the Montreal-Lake Ontario section has a channel width of less than 500 ft. The narrowest sections are amenable to the provision of additional fixed aids, which provide the necessary guidance information even in periods of very limited visibility. The wider areas do not lend themselves to this solution, however, and are prime candidates for an electronic system.

Removal of the floating, lighted aids in the fall and the delay of their commissioning in the spring result in 1 to 5 weeks of daylight-only navigation, with an attendant reduction of about 75 percent in system capacity and an approximate 100 percent increase in the normal 22- to 24-hr transit time between Montreal and Lake Ontario. An additional 8 to 10 days is lost due to delays during the normal season, for a total economic loss to the Seaway user of about $10 million in increased operating costs due to vessel delays. Full recovery and utilization of the annual lost capacity could result in revenue increases on the order of $10 million per year to the two Seaway entities. Thus, provision of a true, all-weather navigation system on the St. Lawrence River could, in the ideal case, capture annual benefits of up to $20 million, which would be divided about equally between the users and the operating entities.

The availability of a Precise Navigation System is considered by the two Seaway entities to be an essential prerequisite to any extension of the navigation season. However, as is obvious from the above, the need for such a system is clearly justified within the context of firming up the existing navigation season, and is being pursued for that reason.

The provision of navigation aids and vessel traffic control services has significant legal implications with respect to potential liability on the part of the entities for the safety of the vessel, their contents, and their crews. These implications must be considered when contemplating any changes in the services provided. Ideally, some means for a vessel master to verify the accuracy and reliability of his guidance information should be provided so as not to infringe upon his responsibility for the safety of his vessel.

CURRENT STATUS

An international, interagency steering committee, comprised of the two Seaway entities and the two Coast Guards, was established 2 years ago to formalize the mechanism for coordination and cooperation on the Seaway precise navigation problem. This arrangement builds on the significant experience of the U. S. Coast Guard with LORAN-C piloting systems, for COGLAD on up to PILOT and PLAD, which have been demonstrated rather extensively on the St. Marys River, between Lakes Superior and Huron, and on Delaware Bay, respectively. Major tasks for the group include:

a. Definition of system accuracy and reliability requirements.

b. Examination of the potential role of LORAN-C.

c. Survey of other candidate positioning systems.

d. Development of requirements for the shipboard display unit.

e. Recommendations to management on a Seaway Precise Navigation System.

PRELIMINARY CONCLUSIONS

Preliminary conclusions include:

a. The St. Lawrence Seaway precise navigation problem is relatively unique and technically demanding.

b. No single electronic positioning system currently available can provide the necessary combination of accuracy and reliability required to allow all-weather vessel movements throughout the Montreal-Lake Ontario portion of the system in the absence of conventional navigation aids.

c. The current accuracy requirement is estimated by the Seaway entities at just under ±25 ft, absolute.

d. The accuracy and reliability requirements for a replacement system must be expressed in absolute, rather than probabilistic, terms since no vessel master can be asked to subject his vessel to a 5 percent or even a 1 percent probability of grounding or collision.

e. To meet stringent Seaway reliability requirements, a combination of additional conventional aids (more ranges and fixed lights) and two or more additional systems will most likely be needed.

f. Radar will likely be one of the component systems, and an integrated display is highly desirable, if not required, for user acceptance.

Based on preliminary results of ongoing grid monitoring and field testing activities, it is clear that, even with some form of differential corrections, the present Northeast LORAN-C chain cannot provide the accuracy necessary for safe navigation in the Montreal-Lake Ontario section of the St. Lawrence River. However, installation and operation of a LORAN-C transmitter north of the River could significantly improve grid geometry to the point that LORAN-C might provide the necessary accuracy.

We have been unable to identify any other currently available, off-the-shelf system capable of solving the problem, although a number of available systems could provide useful supplemental information to the St. Lawrence Seaway navigator.

Systems which are examined for their potential contribution include PRANS (Precise Radar Navigation System), Racons (Radar Beacons), MLS (Microwave Landing Systems), sonar positioning systems, follow-the-wire systems, various electronic positioning systems such as LORAN-C and Raydist-T, several microwave systems, laser systems, and night vision enhancement devices.

The Navstar Global Positioning System (G.P.S.) currently under deployment by the U. S. Department of Defense is another candidate system under consideration. Utilizing differential techniques, some sources claim to be able to achieve accuracies on the order of 0.2 m with G.P.S. Accuracies at this level would make G.P.S. a prime candidate for both precise navigation and maintenance uses.

MEASUREMENT OF NUTRIENT CONCENTRATIONS IN SEDIMENT PORE WATER COLLECTED BY A DIALYSIS SAMPLER

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ABSTRACT

In the release mechanism of nutrients it sometimes becomes necessary to investigate the behavior of nutrients in sediment pore water. In the past, the separation of pore water from sediment has been performed using the centrifuge or a filter press procedure. These methods release nutrients dynamically by artificial forces duri g water separation. However, the release action is static in nature. Differences in the release action of nutrients from sediment pore waters using a dynamic (centrifuge) versus a static (dialysis) method will have a large effect on the results. Dynamic separation methods may not accurately reflect the actual static nutrient release processes occurring in nature. To solve this problem, a static separation was developed using a dialysis sampler. This paper discusses results obtained from such a sampler tested in a Japanese lake and a bay.

PORE WATER SAMPLER

The pore water sampler used (Figure 1) was manufactured in Japan according to Mayer (1976). It consists of an acrylic cylinder 60 mm in diameter and 715 mm long, perforated with 10-mm holes on its surface.

The cylinder is divided into six chambers, into which dialysis bags are placed (Figure 2). The sampler is inserted into the sediment and left until the deionized water inside the dialysis bag reaches equilibrium with the pore water of sediment (Figure 3). Then, the sampler is withdrawn and the pore water is analyzed.

MEASURED VALUES OF NUTRIENT CONCENTRATIONS

Measurements of nutrient pore water concentrations were conducted at two locations, Kasumiga Lake (three samples) and Mikawa Bay (two samples). Additional comparisons were made with sediment samples collected at the same location as those of the pore water (dialysis) samples. These samples were analyzed by conventional methods using centrifugal separation. The results of these analyses are shown in Tables 1 and 2.

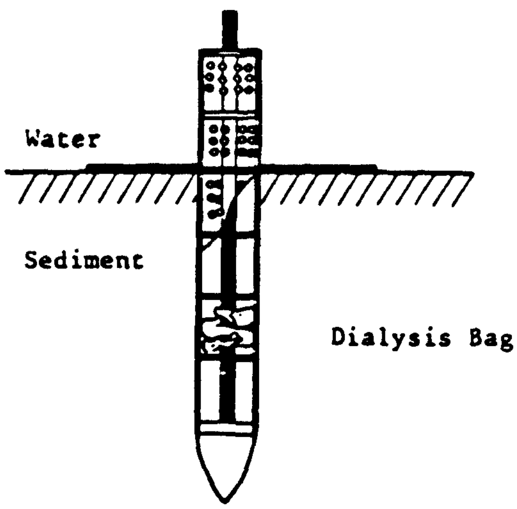


Figure 1. Dialysis sampler developed by Mayer (1976)

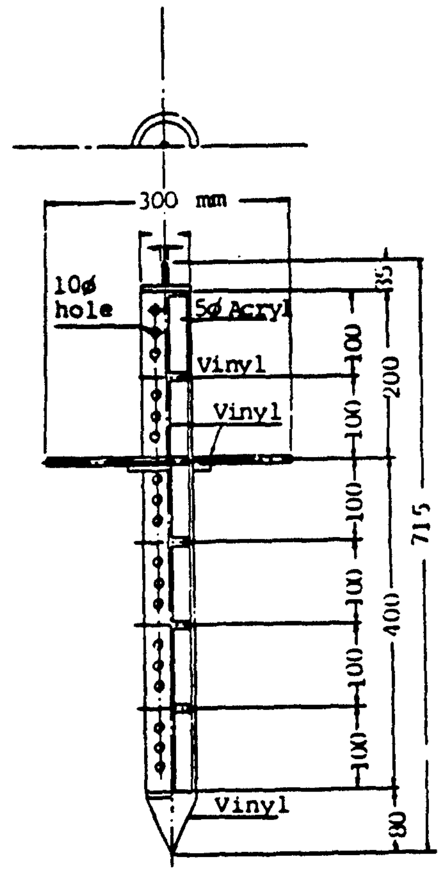
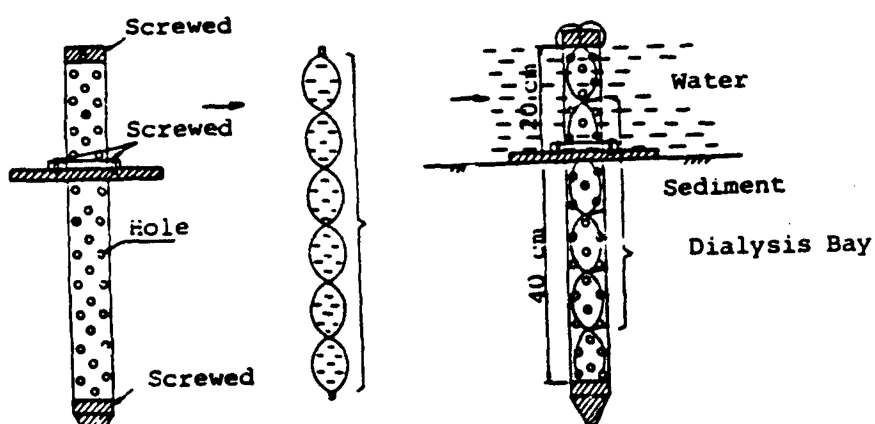


Figure 2. Pore water sampler used



Fill bag with deionized water and separate into six compartments with nylon thread.

Figure 3. Preparing membrane

TABLE 1. NUTRIENT CONCENTRATIONS IN PORE WATER AT KASUMIGA LAKE

	19 Sept. 1981 Centrifuge, mg/ℓ			29 Sept. 1981 Dialysis, mg/ℓ			5 Oct. 1981 Dialysis, mg/ℓ		
Depth, cm	PO_4-P	NH_4-N	Cl^-	PO_4-P	NH_4-N	Cl^-	PO_4-P	NH_4-N	Cl^-
				Off-Shore Takasaki, Water*					
10-20	-	-	-	0.017	0.04	12	-	-	-
0-10	-	-	-	0.014	0.14	10	-	-	-
				Off-Shore Takasaki, Sediment					
0-10	0.01	14.9	22	0.011	1.20	12	-	-	-
10-20	0.024	10.5	24	0.008	1.18	12	-	-	-
20-30	0.030	8.65	24				-	-	
30-40	0.76	7.35	27				-	-	
				On-Shore Kawaguchi, Water*					
10-20	-	-	-	0.008	0.11	29	0.026	0.63	-
0-10	-	-	-	0.014	0.43	29	-	-	-
				On-Shore Kawaguchi, Sediment					
0-10	0.014	34.2	41	0.008	16.3	27	-	-	-
10-20	0.014	53.3	40	0.008	33.0	29	0.017	33.3	-
20-30	0.060	72.7	43	0.011	40.0	28	0.045	40.4	-
30-40	0.235	75.8	53	0.012	43.2	30	-	-	-

* Water depth expressed as sample collection point relative to sediment surface.

TABLE 2. NUTRIENTS CONCENTRATIONS IN PORE WATER AT MIKAWA BAY

	11-31 Aug. 1981 Dialysis, mg/ℓ		9-23 Dec. 1981 Dialysis, mg/ℓ		18-25 Feb. 1982 Dialysis, mg/ℓ		31 Aug. 1981 Centrifuge, mg/ℓ	
Depth, cm	PO_4-P	NH_4-N	PO_4-P	NH_4-N	PO_4-P	NH_4-N	PO_4-P	NH_4-N
				Water*				
10-20	0.516	1.56	-	-	0.006	0.22	0.069	0.336
0-10	0.653	2.11	-	-	0.010	0.22	0.069	0.391
				Sediment				
0-10	1.061	2.44	0.08	1.56	0.010	0.33	1.858	6.16
10-20	2.21	9.00	0.525	7.07	0.432	1.55	1.784	7.78
20-30	2.70	8.74	0.437	2.42	0.634	3.32	1.701	8.12
30-40	1.68	8.07	0.153	2.20	0.759	4.18	1.491	8.53

* Water depth expressed as sample collection point relative to sediment surface.

The vertical distributions of nutrients in pore water using the dialysis sampler are indicated clearly in Figures 4 and 5. The concentrations increase with sediment depth.

It is readily apparent that the two nutrient depth profiles depicted in Figures 4 and 5 show similar patterns of increasing concentration with depth. The profile depicted describes the close relationship generally associated with nutrient release behavior in sediment pore water.

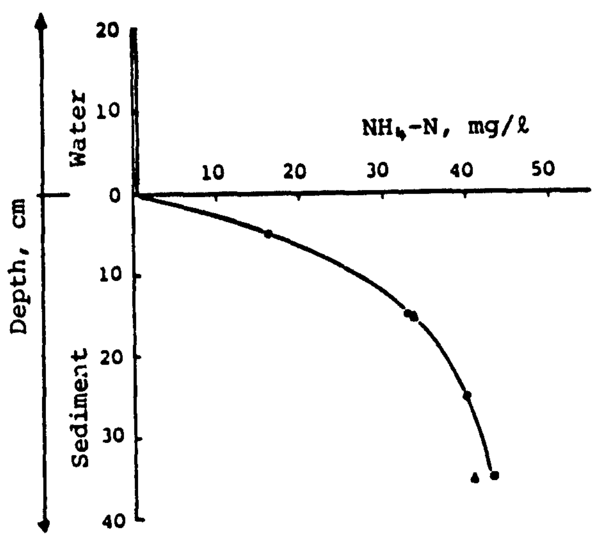


Figure 4. NH_4-N in pore water at Kasumiga Lake

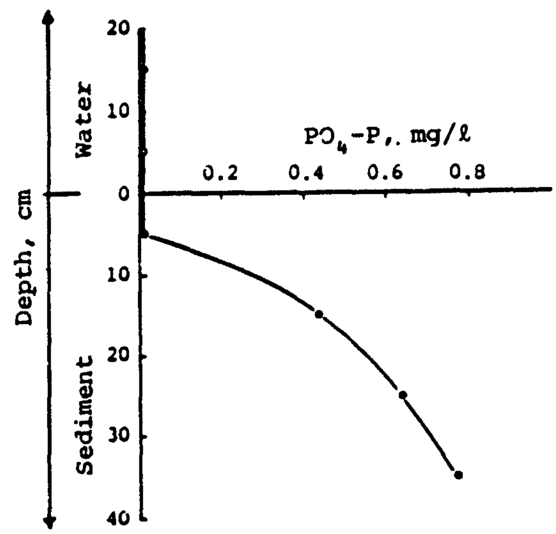


Figure 5. PO_4-P in pore water at Mikawa Bay

COMPARISON OF CENTRIFUGE AND DIALYSIS SEPARATIONS

Differences between centrifuge and dialysis separation methods for Kasumiga Lake sediment are shown in Figure 6.

As the figure shows, the measured concentrations from centrifuge separation are larger than those using the dialysis sampler. This suggests that nutrients are released dynamically during the centrifuge separation. Therefore, the centrifuge method does not suggest an accurate measure of the nutrient concentrations actually found statically in sediment pore waters in nature.

Figure 7 illustrates graphically the differences between the centrifuge method and dialysis method over a range of PO_4-P concentrations measured in sediment pore waters. The larger the magnifying power, the smaller the PO_4-P concentrations. The magnification for NH_4-N is shown in Figure 8. It behaves the same as PO_4-P. In 1983 we conducted the same tests in Tokyo Bay. Figures 9 and 10 indicate the magnifying powers for Tokyo Bay sediment. As the figures show, the magnifying power curves for Tokyo Bay sediment behave the

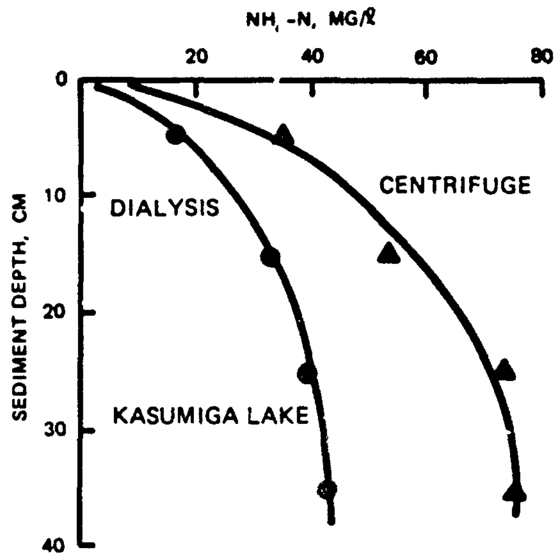


Figure 6. Comparison of NH_4-N from centrifuged and dialysis separated sediments from Kasumiga Laka

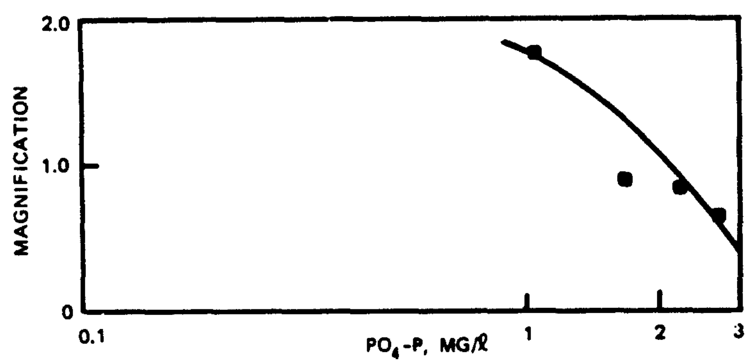


Figure 7. Magnifying power ratio $= \frac{\text{Centrifuge}}{\text{Dialysis}}$ for PO_4-P

same as the ones observed in this paper. Therefore, we have come to believe that the large differences between the two methods might be caused by dynamic release during the centrifuge separations.

THEORETICAL CONSIDERATIONS ON VERTICAL DISTRIBUTION OF NUTRIENTS IN PORE WATER

In Figures 11 and 12, the vertical distributions of nutrient concentrations in sediment are indicated.

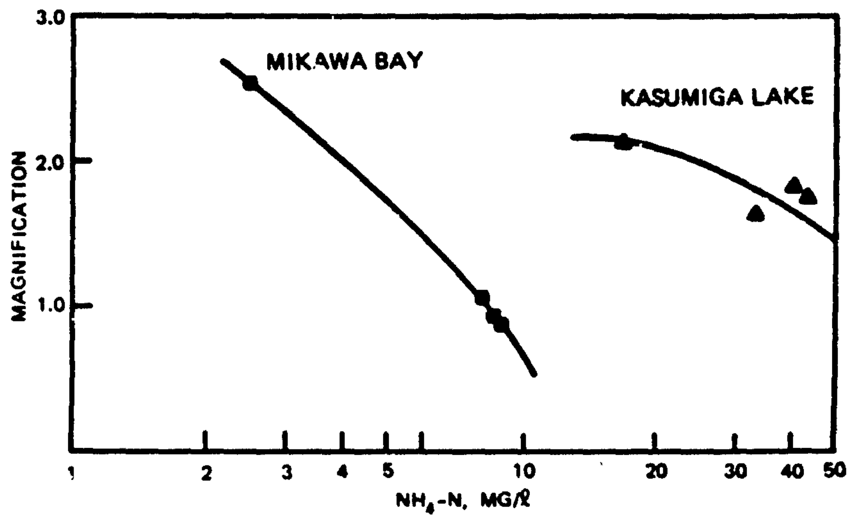


Figure 8. Magnifying power for NH_4-N

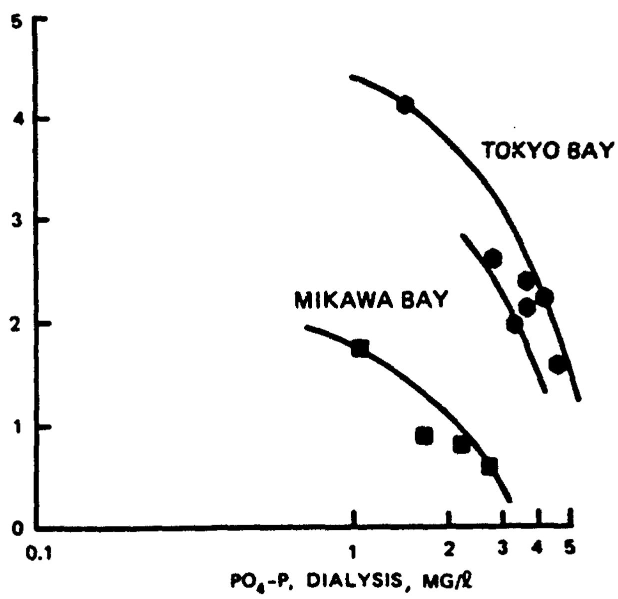


Figure 9. PO_4-P in Tokyo Bay

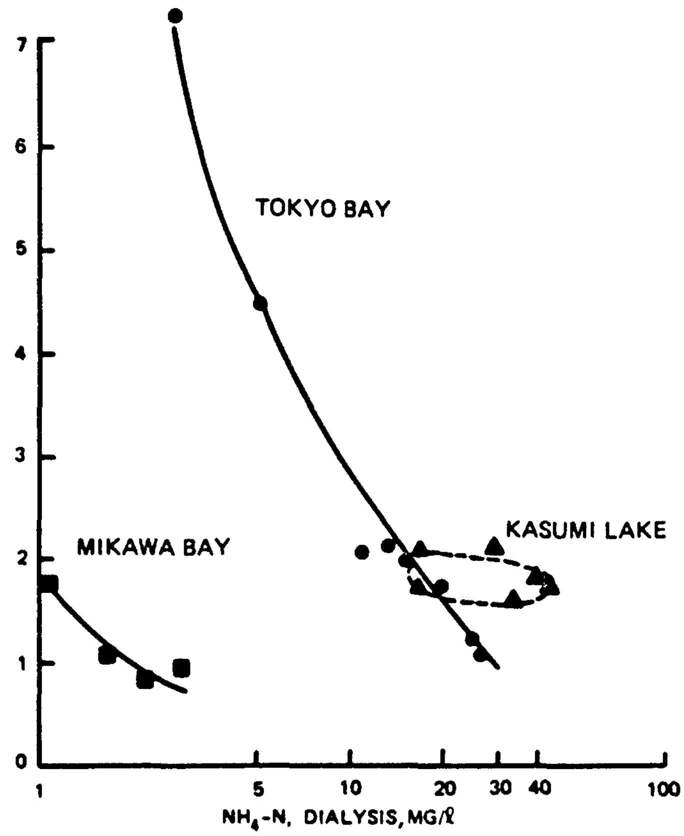


Figure 10. NH_4-N in Tokyo Bay

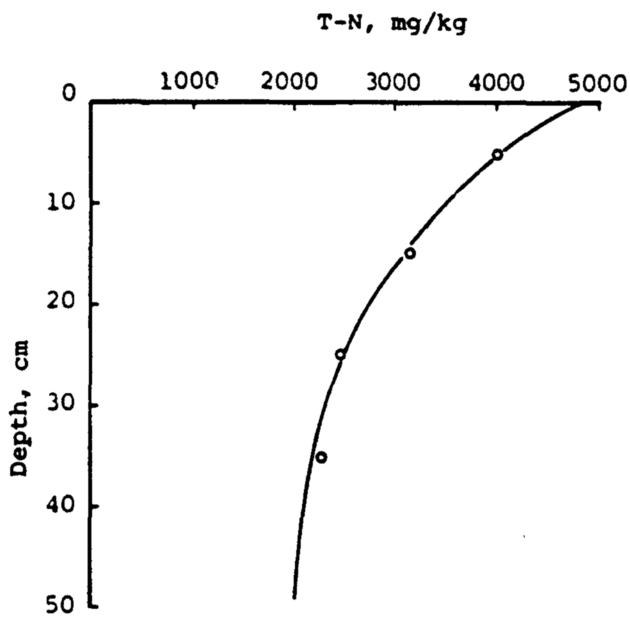


Figure 11. Vertical distribution of T-N in Mikawa Bay sediment

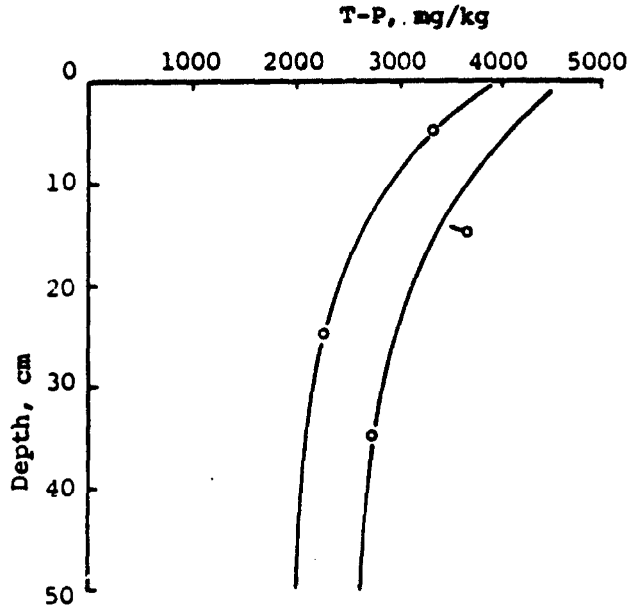


Figure 12. Vertical distribution of T-P in Kasumiga Lake sediment

We can assume that the profile of nutrient distribution Ps is a parabolic curve as follows (also see Figure 13):

$$Ps = P_B + \frac{(Z_B - Z)^2}{2f_p} \text{ mg/kg} \qquad (1)$$

where

P_B = concentration at the point where the curve becomes vertical

Z_B = sediment depth corresponding to P_B

f_p = coefficient of parabola

The quantities of nutrients W, which are contained in the small depth dz at depth Z, are represented as follows (in milligrams):

$$W(Z) = \frac{0.0026}{1 + e_0} Fdz \left[P_B + \frac{(Z_B - Z)^2}{2f_p} \right] \qquad (2)$$

where e_0 = void ratio of sediment.

The quantities of released nutrients, which partition from the above mentioned portion, are represented as follows (in milligrams per day):

$$\xi W = \frac{0.0026}{1 + e_0} F\xi dz \left[P_B + \frac{(Z_B - Z)^2}{2f_p} \right] \tag{3}$$

where

ξ = partition coefficient day^{-1}

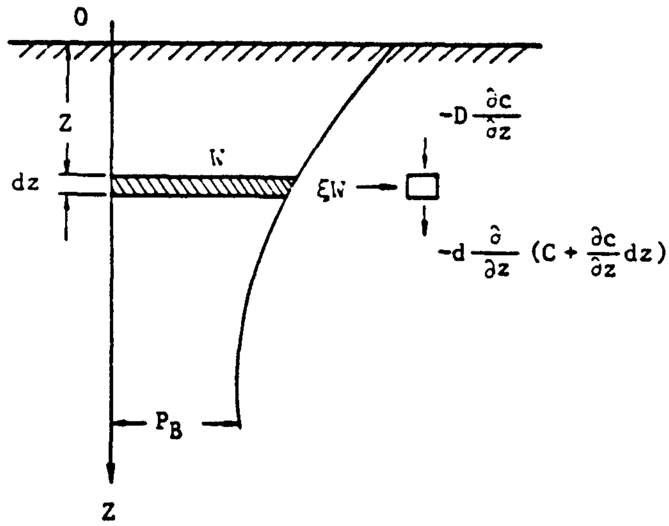


Figure 13. Profile of a nutrient

The equilibrium equation of nutrients at depth z becomes as follows:

$$\frac{\partial c}{\partial t} = \frac{0.0026}{1 + e_0} \xi \left[P_B + \frac{(Z_B - Z)^2}{2f_p} \right] + \frac{\partial^2 c}{\partial z^2} \tag{4}$$

where D = diffusion coefficient of nutrient particles in the vertical direction. If we put here

$$\alpha = \frac{0.0026}{1 + e_0} \xi$$

Equation 4 becomes

$$\frac{\partial c}{\partial t} - D\frac{\partial^2 c}{\partial z^2} = \alpha\left[P_B + \frac{(Z_B - Z)^2}{2f_p}\right] \tag{5}$$

As equation 5 is an irreducible partially differential equation, the solution can be written as follows:

$$C = \sum_{i=1}^{\infty} Ae^{b_i^2 D\cdot t + b_i^2 \cdot z} \tag{6}$$

The particular integral becomes

$$\begin{aligned} C &= \iint -\frac{\alpha}{D}\left[P_B + \frac{(Z_B - Z)^2}{2f_p}\right] dZ\cdot dz \\ &= \int \frac{\alpha}{D}\left[P_B Z - \frac{(Z_B - Z)^3}{6f_p}\right] dz \\ &= -\frac{\alpha}{D}\left[\frac{1}{2} P_B Z^2 + \frac{(Z_B - Z)^4}{24f_p}\right] \end{aligned} \tag{7}$$

Hence, we have the following equation:

$$C = \sum_{i=1}^{\infty} Ae^{b_i^2 D\cdot t + b_i^2 \cdot Z} - \frac{\alpha}{D}\left[\frac{1}{2} P_B Z^2 + \frac{(Z_B - Z)^4}{24f_p}\right] \tag{8}$$

The first term on the right side of Equation 8 is an exponentially increasing function; the second term is a decreasing function with regard to Z .

Figure 14 shows the theoretical distribution calculated by Equation 8 for Kasumiga Lake sediment. There is a good agreement between calculated and measured profiles. This verifies the hypothesis adopted in the preceding calculation.

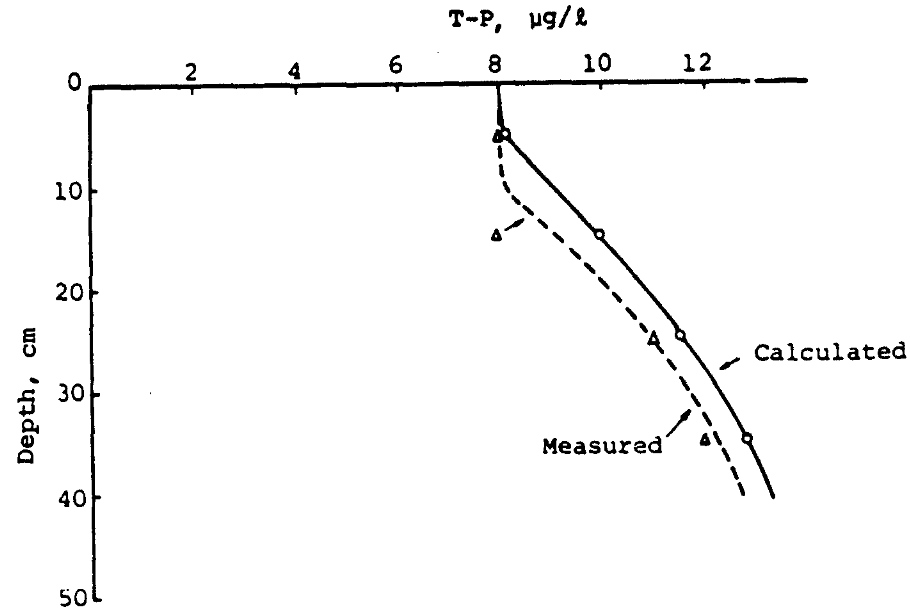


Figure 14. Comparison of measured and calculated values

CONCLUSIONS

Japan was the first country to study measurements using the Mayer (1976) dialysis sampler. These studies gave good suggestions for release mechanisms. It has been concluded that nutrient concentrations in pore water shoul' be measured by such a sampler, and that the conventional method of using a centrifuge is not suitable.

ACCUMULATION OF ACRYLAMIDE INTO FISH

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ABSTRACT

The accumulation of acrylamide monomer and polymer into fish and the behavior of acrylamide monomer in the aqueous environment were investigated. Red sea bream and carp were used as experimental fish. Fishes were placed in fish-rearing tanks with fresh water and/or seawater containing acrylamide monomer and/or polymer and were reared for 25 days. The accumulation of acrylamide monomer into red sea bream from seawater containing 10 ppm acrylamide monomer reached 1.2 ppm after 20 days. Acrylamide monomer accumulated in organs of carp from water by the following factors: liver--0.5, kidney--0.5, gills--0.15, muscle--0.17, and blood--0.19. The degradability of acrylamide monomer in tap water and distilled water was slight. Approximately 90 percent of the acrylamide monomer in seawater and pond water was degraded after 14 days. Acrylamide monomer in fish breeding water decreased to undetectable levels in 5 days. From this experiment, it was clear that the rate of accumulation of acrylamide into fish was slight, and acrylamide monomer in environmental water was easily degradable.

INTRODUCTION

Acrylamide polymer is widely used as a coagulant for treatment of industrial wastewater, domestic sewage, effluent of reclamation, sludge, and dredging work, etc. The toxicity of acrylamide polymer is slight, but acrylamide monomer contained in polymer as a contaminant is neurotoxic. The use of acrylamide monomer in a coagulant invites serious problems for human health. The toxicity of acrylamide monomer is well known and many papers have been written (1-15). However, there are few reports on the biodegradability and the bioaccumulation of acrylamide monomer, and an analytical method of acrylamide monomer accumulation in fish tissue was not known previously. Therefore, it is important to understand the behavior of acrylamide monomer contained in coagulant on the environment. The authors of this paper have investigated analytical methods for acrylamide monomer in tissue and the accumulation of acrylamide monomer in carp and killifish. These results were

reported at the meeting last year (16). In order to determine the behavior of acrylamide monomer in the environment, bioaccumulation and biodegradability were investigated in this paper.

ACCUMULATION OF ACRYLAMIDE MONOMER AND POLYMER IN FISH

Experimental Method

Red Sea Bream (*Chrysophrys major*)

Red sea bream (length: 15.0-20.0 cm, weight: 60-100 g, age: 2 years) were used. One thousand litres of filtered seawater was poured into two 1000-ℓ fish-rearing tanks (A and B, respectively). Ten grams of acrylamide monomer was added to tank A (10 ppm) and 20 g of acrylamide polymer was added to tank B (20 ppm, containing 0.002 ppm of monomer). Thirty red sea bream were put into each tank and reared for 25 days without feeding. Aeration was continued during the experiment. Rearing water was replaced with fresh prepared water containing acrylamide every day.

Five hundred litres of filtered seawater was poured into a 500-ℓ fish-rearing tank (C) and 15 red sea bream were put into tank C and reared for 25 days without feeding. Tank C was used as a control. Aeration was continued during the experiment. Rearing water was replaced with fresh prepared water every day. Water temperature was maintained at 17-22°C during the experiment.

Five red sea bream were selected from each tank at days 0, 5, 10, 15, 20, and 25. Each sample of fish was homogenized and the concentration of acrylamide monomer in the homogenate was measured by the method described below.

Red sea bream was cut up and placed in a homogenizer with distilled water equivalent to the weight of fish and homogenized. A known weight of homogenate was taken and the volume of homogenate was adjusted to 50 ml by addition of distilled water. The pH of the homogenate was adjusted to 1 by addition of 6 N sulfuric acid. Fifteen grams of potassium bromide was added to the homogenate and the homogenate was stirred until the potassium bromide dissolved completely. Then 10 ml of 0.1 M potassium bromate was added to the homogenate, the homogenate was transferred to the refrigerator (5°C) immediately, and the homogenate was stored for 30 min. After bromination (Figures 1 and 2), bromine remaining in the homogenate was removed by addition of 1 M sodium thiosulfate solution. The homogenate was centrifuged for 2 min at 3000 rpm at 5°C; the supernatant was transferred to a separatory funnel; 50 ml of benzene was added to the supernatant; and the separatory funnel was shaken for 15 min. The benzene layer was separated from the water layer. The benzene layer was transferred to another separatory funnel; 50 ml of distilled water was added to the benzene layer; and the separatory funnel was shaken for 15 min. The water layer was then separated from the benzene layer. The water layer was transferred to another separatory funnel; 50 ml of ethylacetate was added to the water layer; and the separatory funnel was shaken for 15 min. The ethylacetate layer was then separated from the water layer. The concentration of 2,3-dibromopropionamide (DBPA) formed by bromination of acrylamide monomer was measured by gas chromatograph and the concentration of

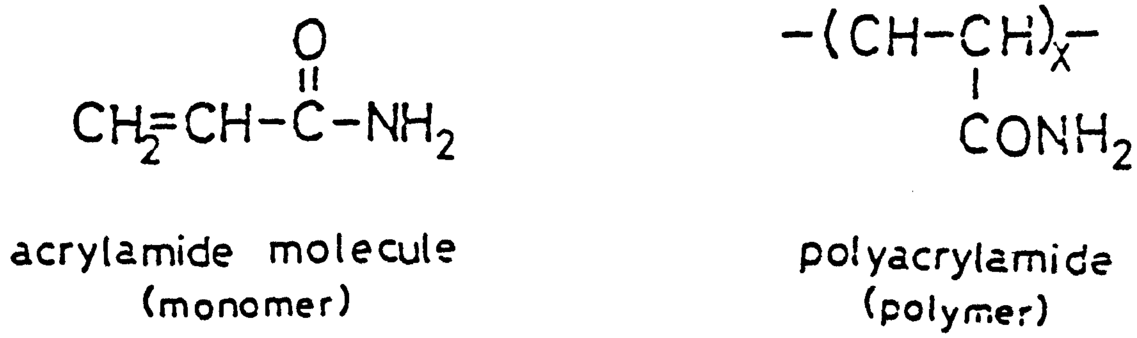

Figure 1. Structure of acrylamide monomer and polymer

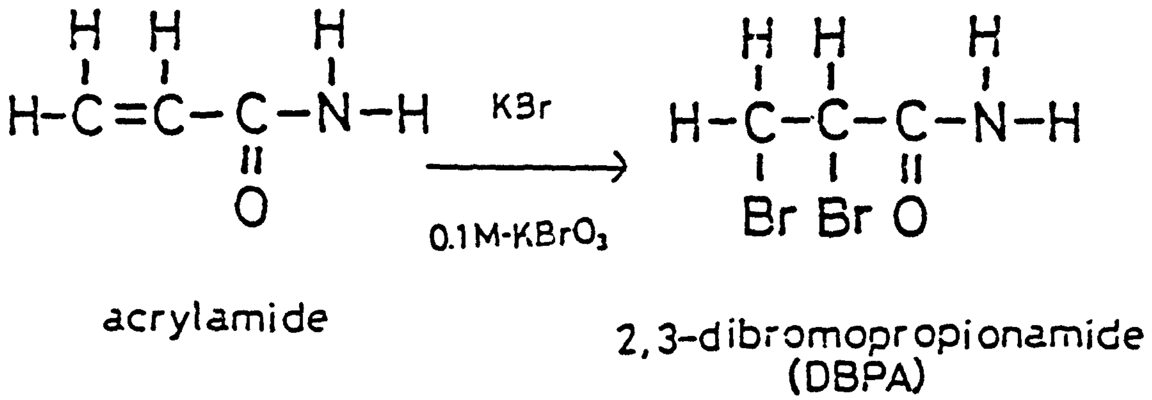

Figure 2. Bromination of acrylamide monomer

acrylamide monomer in the fish tissue was calculated from the concentration of DBPA. The rate of recovery for acrylamide monomer by this method is shown in Table 1.

A gas chromatograph with electron capture detector (Shimadzu GC-7A) was used with a glass column (length: 1000 mm, diameter: 3 mm) packed with Silicone OV-275 (2%, support: Chromosorb W. 80-100 mesh). Column and detector temperatures were 175°C and 190°C, respectively. Nitrogen gas was used for carrier gas and the flow rate was 35 ml/min.

TABLE 1. RATE OF RECOVERY OF ADDED 10 ppm ACRYLAMIDE MONOMER TO HOMOGENATE OF FISH TISSUE*

Rate of recovery	12.96%
	12.13
	12.95
	11.19
	11.07
Mean	12.06
Standard deviation	0.91
Coefficient of variation	7.56

* Extraction: benzene-water-ethylacetate.

Carp (*Cyprinus carpio*)

Carp (length: 15.0–20.0 cm, weight: 80–100 g) were used. Forty litres of distilled water was poured into three 40-ℓ fish-rearing tanks (D, E, and F, respectively). Four hundred milligrams of acrylamide monomer was added to tank D (10 ppm) and 2000 mg of acrylamide monomer was added to tank E (50 ppm). Tank F was used as a control. Thirty carp were put into each tank and reared for 20 days without feeding. Carp in tank D were reared for an additional 5 days without feeding after the experimental dosing with acrylamide monomer ended.

Aeration (600 ml/min) was continued during the experiment. Rearing water was replaced with fresh prepared water containing acrylamide every day. Water temperature was maintained at 20°–22°C during the experiment. Three carp were selected from each tank at days 0, 5, 10, and 20. The liver, kidney, gills, muscle, and blood of these carp were homogenized separately and the concentration of acrylamide in the homogenate was measured by the method described as follows.

Organs without blood were cut up and placed in a homogenizer with distilled water equivalent to the weight of tissue homogenized. A known weight of homogenate was taken and the volume of homogenate was adjusted to 50 ml by addition of distilled water. The pH of the homogenate was adjusted to 1 by addition of 6 N sulfuric acid. Fifteen grams of potassium bromide was added to the homogenate and the homogenate was stirred until the potassium bromide dissolved completely. Then 10 ml of 0.1 M potassium bromate was added to the homogenate; the homogenate was transferred to the refrigerator (5°C) immediately; and the homogenate was stored for 30 min. After bromination, bromine remaining in the homogenate was removed by addition of 1 M sodium thiosulfate solution. The homogenate was centrifuged for 2 min at 3000 rpm at 5°C; the supernatant was transferred to a separatory funnel; 50 ml of ethylacetate was added to the supernatant; and the separatory funnel was shaken for 15 min. The ethylacetate layer was then separated from the water layer. The concentration of DBPA in the ethylacetate layer was measured by gas chromatograph and the concentration of acrylamide monomer in the fish tissue was calculated from the concentration of DBPA. The rate of recovery for acrylamide monomer by this method is shown in Table 2.

TABLE 2. RATE OF RECOVERY OF ADDED 20 ppm ACRYLAMIDE MONOMER TO HOMOGENATE OF FISH TISSUE*

Rate of recovery	83.4%
	81.1
	83.4
	80.2
	81.9
Mean	82.0
Standard deviation	1.41
Coefficient of variation	1.72

* Extraction: ethylacetate.

Results

The accumulation over time of acrylamide monomer into red sea bream from seawater containing 10 ppm acrylamide monomer is shown in Figure 3. The accumulation in red sea bream from seawater increased rapidly until day 5 and then slowly until day 20 when the concentration of acrylamide monomer reached 1.2 ppm. The concentration factor of acrylamide monomer from seawater to red sea bream was 0.12.

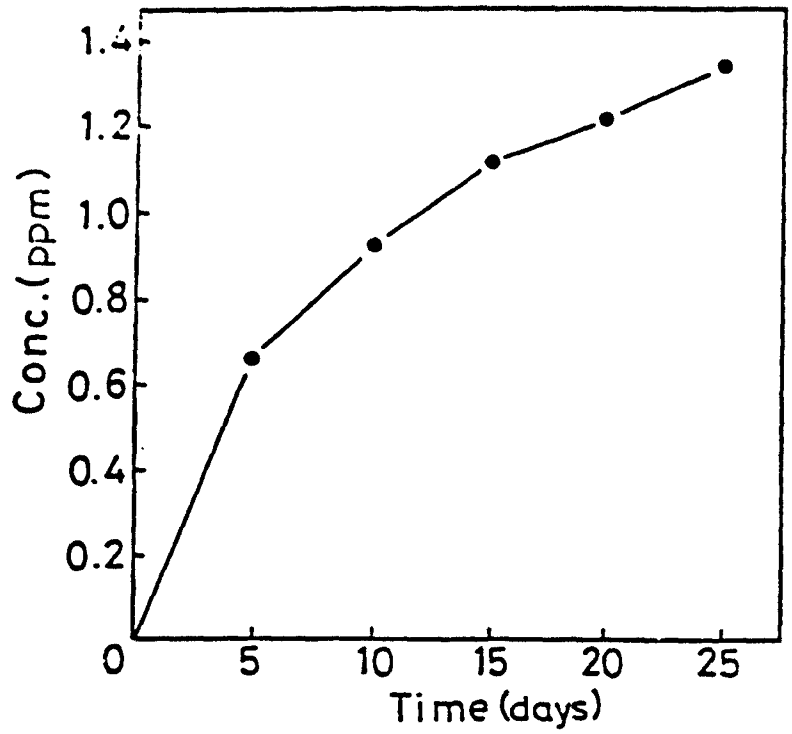

Figure 3. Accumulation of acrylamide in red sea bream in 10 ppm acrylamide monomer solution

The accumulation over time of acrylamide monomer into red sea bream from seawater containing 20 ppm of acrylamide polymer was undetectable during this experimental period. The accumulation over time of acrylamide monomer into carp organs from water containing 10 and 50 ppm of acrylamide monomer is shown in Figures 4 and 5, respectively. The accumulation of acrylamide monomer in carp gills, muscle, and blood from water containing 10 and 50 ppm of acrylamide monomer occurred rapidly and reached equilibrium by day 5. The accumulation in the liver and kidney increased slowly and continuously during the experimental period. The concentration factor from water to liver was 0.5, kidney 0.5, gills 0.15, muscle 0.17, and blood 0.19.

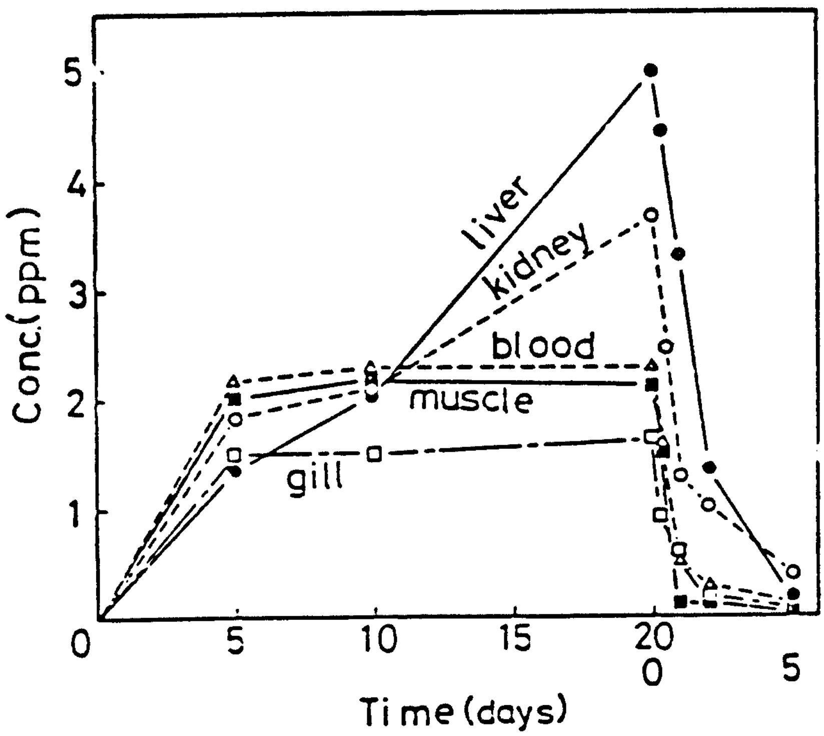

Figure 4. Accumulation and excretion of acrylamide of carp organs in 10 ppm acrylamide monomer solution

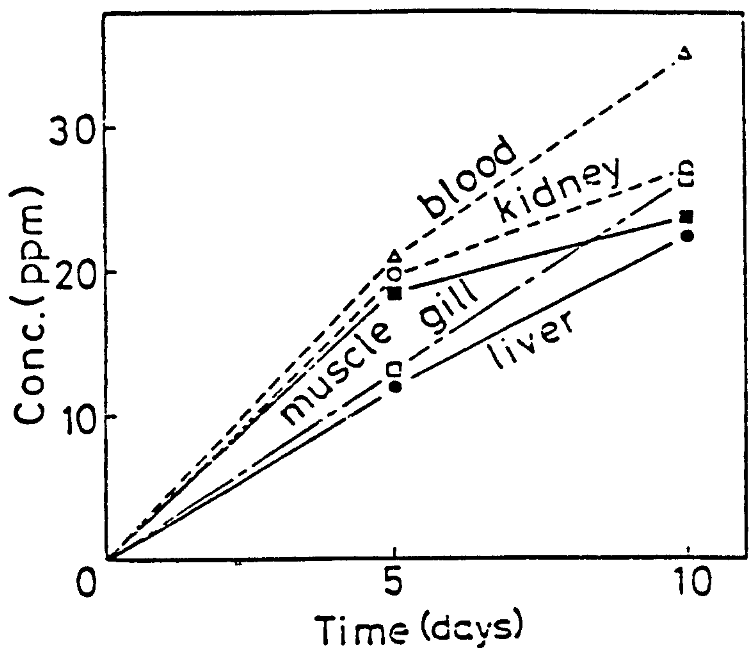

Figure 5. Accumulation of acrylamide into carp organs in 50 ppm acrylamide monomer

DEGRADABILITY OF ACRYLAMIDE MONOMER IN AQUEOUS ENVIRONMENT

Experimental Method

Water

Tap water (from Sakura-mura, Ibaraki-ken), distilled water, seawater (from coast of Oarai, Katsuta-shi, Ibaraki-ken), pond water (from park Matsumi, Sakura-mura, Ibaraki-ken), and breeding water (which was used for rearing of carp) were used in this experiment. Three hundred millilitres of tap water, distilled water, seawater, and pond water was poured into four 300-ml Erlenmeyer flasks, respectively, and then 3 mg of acrylamide monomer was added to each flask. Waters in these flasks were stirred during the experimental period and temperature was kept at 20°C. Breeding water was prepared by the following method. Ten litres of distilled water was placed in a 10-ℓ fish-rearing tank with two carp. Then, 100 mg of acrylamide monomer was added to the tank and temperature was kept at 20°C during the experimental period. Concentration of acrylamide monomer in the tap water, distilled water, seawater, pond water, and breeding water was measured daily.

Carp Tissue

In the experiment on accumulation of acrylamide monomer into carp tissue from the water containing 10 ppm of acrylamide monomer (tank D), the dosage was suspended after 20 days and the carp were reared in acrylamide monomer free water for 5 days. Two carp were taken from tank D at 6 hr, 12 hr, 24 hr, 2 days, and 5 days after suspension of acrylamide monomer dosing. The organs of these carp were homogenized and the concentration of acrylamide in the homogenate was measured by the method previously described for carp.

Results

The degradation over time of acrylamide monomer in waters is shown in Figure 6. Degradability of acrylamide monomer in tap water and distilled water was slight. Approximately 90 percent of the acrylamide monomer in seawater and pond water was degraded after 14 days. Acrylamide monomer in breeding water decreased to undetectable levels after 5 days.

In the experiment on accumulation of acrylamide monomer in carp from water the dosage was suspended after 20 days and the carp were reared in acrylamide monomer free water for 5 days. Organs of carp used in this experiment were sampled and the concentration of acrylamide monomer in the organs was measured as above. Variations of concentration over time are shown in Figure 7. Acrylamide monomer in all organs decreased quickly. After 12 hr, 80 percent of acrylamide monomer in muscle, 70 percent in gills, 60 percent in blood and kidney, and 50 percent in liver were degraded. After 2 days, 95 percent in muscle, 90 percent in gill, 80 percent in blood, 70 percent in kidney, and 70 percent in liver were degraded. After 5 days, 90 percent or more of acrylamide monomer in all organs was degraded.

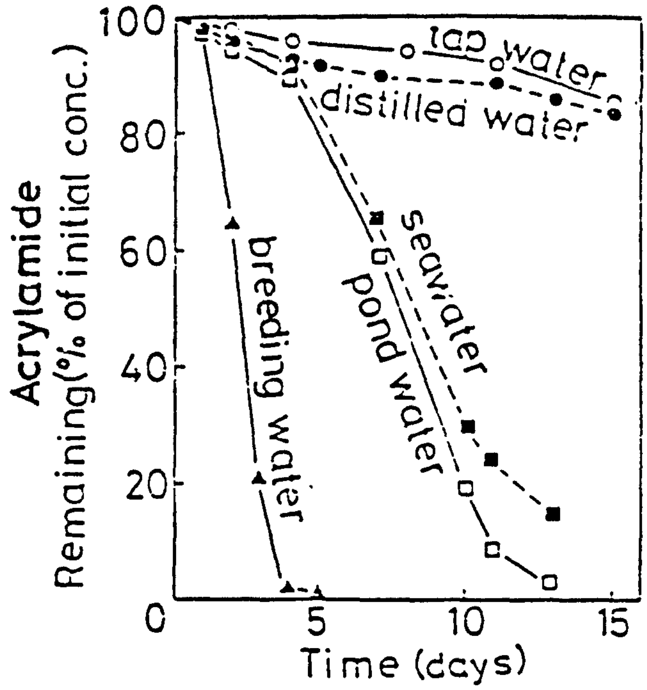

Figure 6. Degradation of acrylamide (10 ppm) in water

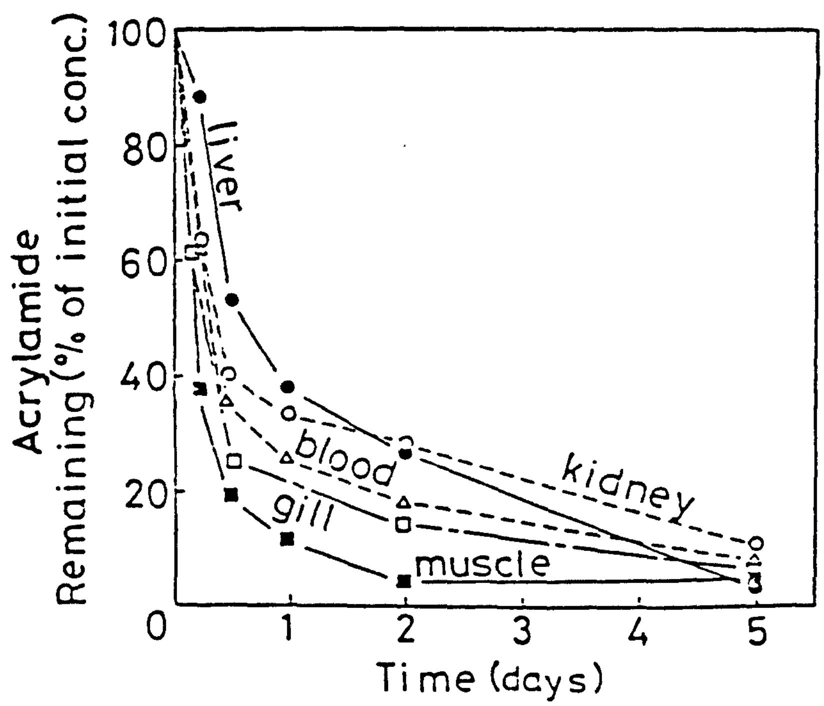

Figure 7. Excretion and degradation of acrylamide in carp organs

DISCUSSION

An analytical method of acrylamide monomer in water has been reported by Croll and Simkins (17), Arimitsu (18), and Nakamura (19). However, an analytical method of acrylamide monomer in fish was not known previously; therefore, the authors of this paper have developed and reported an analytical method for acrylamide monomer accumulated in fish tissue (16). This made it possible to investigate accumulation in fish and biodegradation in the aqueous environment. In order to determine the behavior of acrylamide monomer contained in coagulant in the aqueous environment, accumulation of acrylamide monomer and/or polymer in fish and degradation of acrylamide monomer in the aqueous environment were investigated in this study.

The concentration of acrylamide monomer in red sea bream tissue from seawater containing 10 ppm of acrylamide monomer reached 1.2 ppm after 20 days. The concentration factor was 0.12. This concentration factor was lower than the concentration factor for carp or killifish. The concentration factors for carp and killifish from water containing 10 ppm acrylamide monomer after 20 days were 0.26 and 2.53, respectively (16). Body length and weight of red sea bream, carp, and killifish used in the accumulation experiments were 10-20 cm and 60-100 g, 6-20 cm and 3-35 g, and 2.3-3.3 cm and 0.25-0.29 g, respectively. The concentration factor for large fish was low and for small fish was high (Figure 8). Body weight of red sea bream was related to the concentration of accumulated acrylamide monomer (Figure 9). In this case, the coefficient of correlation was -0.66. From these results, it was concluded that acrylamide monomer was taken up through the surface of the fish's body.

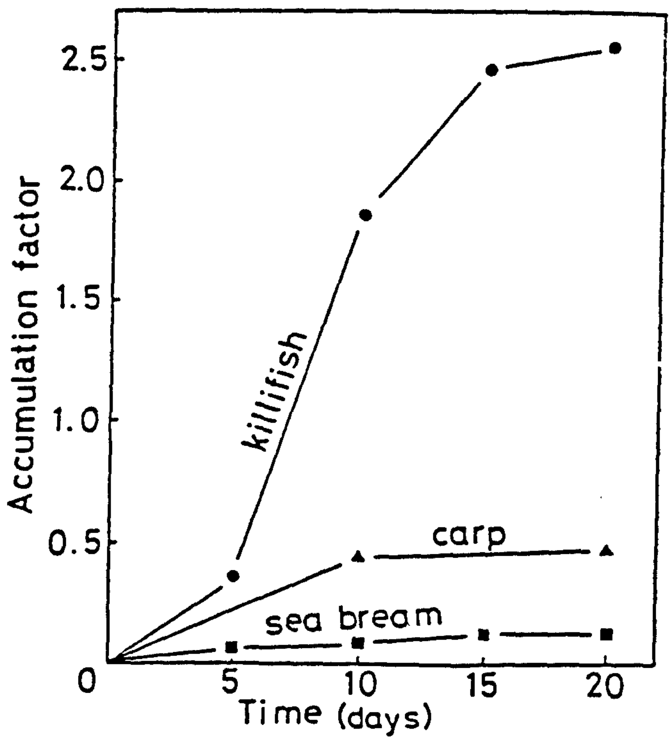

Figure 8. Accumulation of acrylamide into fish in a 10-ppm acrylamide monomer solution

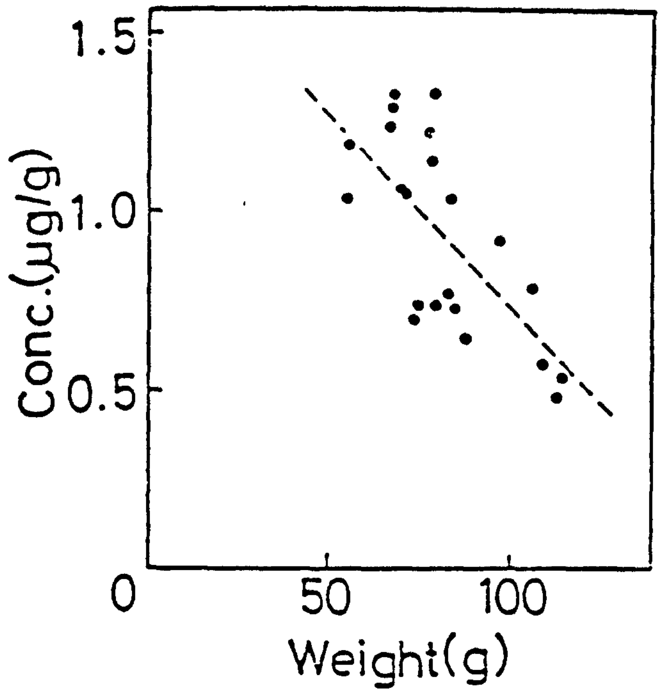

Figure 9. Relationship between body weight of fish and concentration of accumulated

Concentration factor of accumulated acrylamide monomer in fish was far smaller than the concentration factor of methylmercury or PCB in spite of the use of very high concentrations of acrylamide monomer such as 10 ppm in breeding water. The accumulation of methylmercury was reported by Kitamura (20) who stated that 1.07 ppm of methylmercury accumulated into goldfish body from water containing 0.003 ppm of methylmercury after 40 days, giving a concentration factor of approximately 3,500. However, the concentration factor of acrylamide monomer into fish from breeding water was very small. It seems that acrylamide monomer is degraded and/or excreted quickly by organisms. Therefore, biodegradability experiments were conducted. Acrylamide monomer in tap water and distilled water did not decrease significantly; acrylamide monomer in natural seawater and pond water decreased significantly after 7 days; and acrylamide monomer in breeding water in fish-rearing tanks with carp decreased quickly and became undetectable after 5 days. Tap water and distilled water did not contain organisms; however, natural seawater and pond water contained various microorganisms and the breeding water contained various microorganisms and carp. From these facts, it was indicated that organisms in an aqueous environment contribute to degradation of acrylamide monomer and body organs of the carp also contribute to degradation of acrylamide monomer.

After suspension of the acrylamide monomer dosage, the concentration of acrylamide monomer in carp muscle decreased rapidly, the concentrations in kidney and liver decreased slowly, and the concentrations in blood and gills were between kidney and muscle. It seems that acrylamide monomer is carried by blood, metabolized by liver, and excreted by kidney. The concentration

factor of acrylamide monomer for fish is small, and the rate of metabolism and excretion is rapid.

CONCLUSIONS

This investigation has shown that the concentration factor of acrylamide monomer for fish from water containing 10 ppm of acrylamide monomer is very small and the concentration of acrylamide monomer in fish from acrylamide polymer is undetectable. Acrylamide monomer is rapidly degraded by organisms in an aqueous environment. Therefore, it is concluded that the use of acrylamide polymer as a coagulant may not cause serious problems for environmental health.

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LONDON DUMPING CONVENTION UPDATE

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BACKGROUND

The Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter--known as the London Dumping Convention or LDC--was negotiated in London in November 1972. After ratification by 15 member nations, the LDC came into force in the United States on 30 August 1975.

The policy, regulatory, and technical aspects of the Corps of Engineers' and the U. S. Environmental Protection Agency's (EPA) ocean dumping programs for dredged material are directly affected by the United States being signatory to the LDC. Domestic criteria must, at a minimum, be equivalent to and contain all of the basic constraints set forth in the international regulations.

The contracting nations have met annually since LDC-I met in September 1976. At that time, an extensive program of work was adopted related to the implementation of the Convention concerning all aspects of dumping at sea (including the dumping of dredged material).

A Scientific Group was formed to make technical and scientific recommendations to the LDC concerning the ecological aspects of regulating dumping at sea. The group met in September 1977 and has since met annually approximately 6 months prior to each annual LDC meeting.

A Task Team 2000 has been organized to identify long-term goals of the LDC. The team's specific objective is to project the role of the Convention in the Year 2000.

The Deputy Director for the Directorate of Civil Works of the Office, Chief of Engineers (OCE), attends the annual meetings of the LDC as the Corps' policy representative. Dr. Robert M. Engler of the U. S. Army Engineer Waterways Experiment Station (WES) is the Corps' technical representative at both LDC and Scientific Group meetings.

LDC-VII

The LDC-VII met in London on 14-18 February 1983. Delegates from 32 of the 52 contracting nations were present. There were also 14 observer groups representing countries that anticipate joining the LDC, regional or local conventions, and other parties interested in the international regulation of ocean dumping of waste materials.

The 16-member U. S. delegation to the Convention was headed by Dr. John Hernandez of EPA. The other members of the delegation, who acted as advisors

to Dr. Hernandez, were representatives from the Department of State, the House of Representatives, the Corps (OCE and WES), and the National Oceanic and Atmospheric Administration.

The comprehensive agenda addressed all aspects of ocean dumping and pollution. Agenda items significantly affecting the Corps' dredging and disposal projects were consideration of the report of the September 1982 meeting of the Scientific Group, the report by Task Team 2000, and the discussion of the possible prohibition of ocean disposal of all low-level radioactive materials. These are discussed in the following paragraphs.

Scientific Group Report

Two major items from the report concerned Corps projects: the possible inclusion of lead on the Annex I list of materials prohibited from ocean disposal as other than trace contaminants, and the use of capping or other special care techniques in ocean disposal of contaminated sediments. The issue of inclusion of lead was scheduled to be resolved technically at the meeting of the Scientific Group in October 1983 and to be acted upon at the policy level by the LDC-VIII in February 1984. At present, lead is an Annex II material that is not prohibited from ocean disposal, but must be given special care when disposed in significant amounts. Dredged material contains high natural background levels of lead (in comparison to mercury and cadmium, which are prohibited by Annex I) and thus inclusion of lead in Annex I could result in significant practical problems in implementing the LDC. Moreover, lead is generally stable in dredged material and the marine environment.

The LDC-VII was also asked by the Scientific Group to consider whether or not dredged material contaminated with Annex I (prohibited) substances can be capped with clean material under the provisions of the LDC. It was generally agreed that capping techniques should be studied as field research and projects monitored until sufficient information is obtained as to the acceptability of capping from a scientific viewpoint. The Corps' research under the Environmental Effects of Dredging Program (EEDP) will continue to assess the technical applicability of capping in various aquatic environments. At some future meeting of the LDC, the full legal acceptability of capping will be debated with a goal of modifying the LDC rules and regulations if capping proves technically feasible.

Task Team 2000

The general finding of the Task Team was that the ultimate goal of the LDC could be stated quite simply as to "protect the marine environment." However, the team did not regard the attainment of such a goal in the black and white terms of opting either to eliminate any ocean dumping activity or to control waste disposal at sea. It was, however, recognized that for some categories of waste, ocean disposal would continue to be a normal option, for example, the dumping at sea of uncontaminated dredged material and sewage sludge. The U. S. delegation endorsed the view that ocean disposal should be considered as an acceptable alternative disposal technique where the decision to utilize ocean disposal is made after assessing alternatives in each situation.

Low-Level Radioactive Material

The controversial subject of ocean disposal of low-level radioactive material was also considered at LDC-VII. Low-level radioactive wastes are currently Annex II materials that require special care be given the disposal. The delegates from the island countries of Kiribati and Naru jointly proposed the absolute prohibition of ocean dumping of all ratioactive waste or matter regardless of level, form content, or method or containment. The proposed amendment to the LDC Annexes would move low-level radioactive waste to Annex I, which would prohibit ocean disposal. This proposal's absolute and all-inclusive language could, in its broadest context, be interpreted to include dredged material with natural background radiation. After significant debate, the proposed amendment was withdrawn and replaced by a nonbinding resolution of similar language submitted by Spain. The resolution was passed by the LDC with the United States voting against the resolution. In conclusion, there is nothing in the historical language of the LDC, U. S. domestic regulations, or the recent LDC meeting that changes the fact that dredged material is considered nonradioactive for the purposes of international or domestic regulation. The Corps will, however, urge that dredged material be formally classified as nonradioactive for the purposes of regulation.

FUTURE MEETINGS

The Scientific Group will meet in London on 24-28 October 1983. Several major technical issues affecting ocean disposal of dredged material will be discussed: the positions of lead and lead compounds in the annexes to the LDC; interpretation of the term "trace contaminants"; implementation guidelines for Annex II; guidelines for the uniform interpretation of Annex III; oil in dredged material; and definition of so-called "special care" techniques for disposal of contaminated dredged material.

The LDC-VIII will meet in London on 14-18 February 1984 and will consider the policy resolution of the technical issues addressed by the Scientific Group in the October 1983 meeting and other policy level issues affecting legal as well as technical implementation of the LDC.

ALTERNATIVES TO OPEN WATER DISPOSAL OF CONTAMINATED DREDGED MATERIAL

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ABSTRACT

Of the 6 to 7.5 million cubic meters of dredged material generated each year from the New York Harbor Area, 2 to 5 percent has been determined to be unacceptable for unrestricted ocean disposal. Three disposal options are being studied which could accommodate this material: use of dredged material as sanitary landfill cover, upland disposal, and containment areas and islands. In a dewatered state, dredged material could be used as a substitute for traditional cover material at sanitary landfills. Chemical and engineering tests were performed on representative dredged material from New York Harbor, and it was determined that all material is environmentally acceptable and may be economically feasible for this use. Potential upland disposal areas (barren areas) were evaluated using environmental and socioeconomic criteria to eliminate unacceptable sites. Containment area and island siting criteria were developed to eliminate highly biological productive areas in New York Harbor from consideration. Further efforts for all three disposal options are being directed at site availability, social acceptability, and detailed environmental and economic studies. All three options appear to be technically feasible. Sanitary landfill cover may prove to be a use of dredged material as a resource. However, the most problematic aspects of these disposal options involve their social acceptability rather than technical aspects.

INTRODUCTION

In order to maintain the present volume of ship traffic and tonnage, almost 7.5 million cubic meters of sediment has been dredged per year from the Port of New York/New Jersey (NY/NJ) over the past 45 years. The bulk of this material has historically been ocean disposed. The disposal site is located in the New York Bight, about 10 km east of Sandy Hook, N. J.

The possible adverse environmental impact of the dredged material containing potentially toxic and hazardous substances originating from treated and untreated sewage discharges, industrial discharges, urban runoff, and chemical spills has generated considerable concern. This has prompted the scientific and regulatory organizations to reevaluate existing disposal methods and options.

The New York District, Corps of Engineers, now has analyzed more than 150 bioassay/bioaccumulation tests. The analyses indicate that 98 percent of the sediments satisfy the ocean dumping criteria and may therefore be ocean disposed (1).

Of the 6 to 7.5 million cubic meters of material dredged annually from the Port of NY/NJ, approximately 95 to 98 percent is suitable for unrestricted ocean disposal without any adverse environmental impact. Material shown to have a statistically significant uptake of one or more of the contaminants of concern (petroleum hydrocarbons, PCB's, Cd, Hg) requires modification to unrestricted ocean disposal before the material may be safely disposed at sea.

In order to consider ways to dispose of this remaining 2 to 5 percent of "questionable" material, the New York District has developed a comprehensive management plan for dredged material disposal to investigate in detail all options and to incrementally implement the feasible options (2). An intergovernmental steering committee composed of Federal and state regulatory agencies has been established to review all aspects of the management plan. In addition, input from the public is provided through a public involvement group.

The disposal options have been evaluated using the following parameters: engineering, economic, environmental, public health, sociological, and legal/regulatory. Options were then placed in one of three categories. The category, Alternatives Not Currently Reasonable, consists of disposal methods that merit no further consideration because, under present conditions and using existing technology, they could not be implemented, or because they offer no clear advantage over more readily available disposal methods. The second category, Alternatives Possible in Special Cases, includes disposal options that would be of use in certain instances depending on degree of contamination of the dredged material, physical nature of the material, and volumes involved.

The third category, Alternatives Possible in Special Cases and Feasible for Large Volumes of Material, contains those methods most likely to provide adequate disposal of the quantity and quality of the material dredged in the New York District.

In this paper we will discuss the following options for the disposal of "questionable" material: use of dredged material as sanitary landfill cover, upland disposal, and containment areas and islands. These options are not mutually exclusive; any or all of them could be incorporated into the management program.

USE OF DREDGED MATERIAL AS SANITARY LANDFILL COVER

A sanitary landfill is a system for disposing of municipal solid waste by daily filling of a land area with the waste, compaction of the garbage through mechanical methods, and covering the material with a layer of soil (usually 0.3 m per day). The layer of soil is emplaced as daily cover, primarily to prevent disease vectors from being carried from the site by birds and rodents. In addition, sanitary landfill cover acts as a fire retardant and an odor control barrier. Solid waste and cover material are built up in a layer cake effect (Figure 1). Intermediate cover (usually 0.5 m) is emplaced if, for

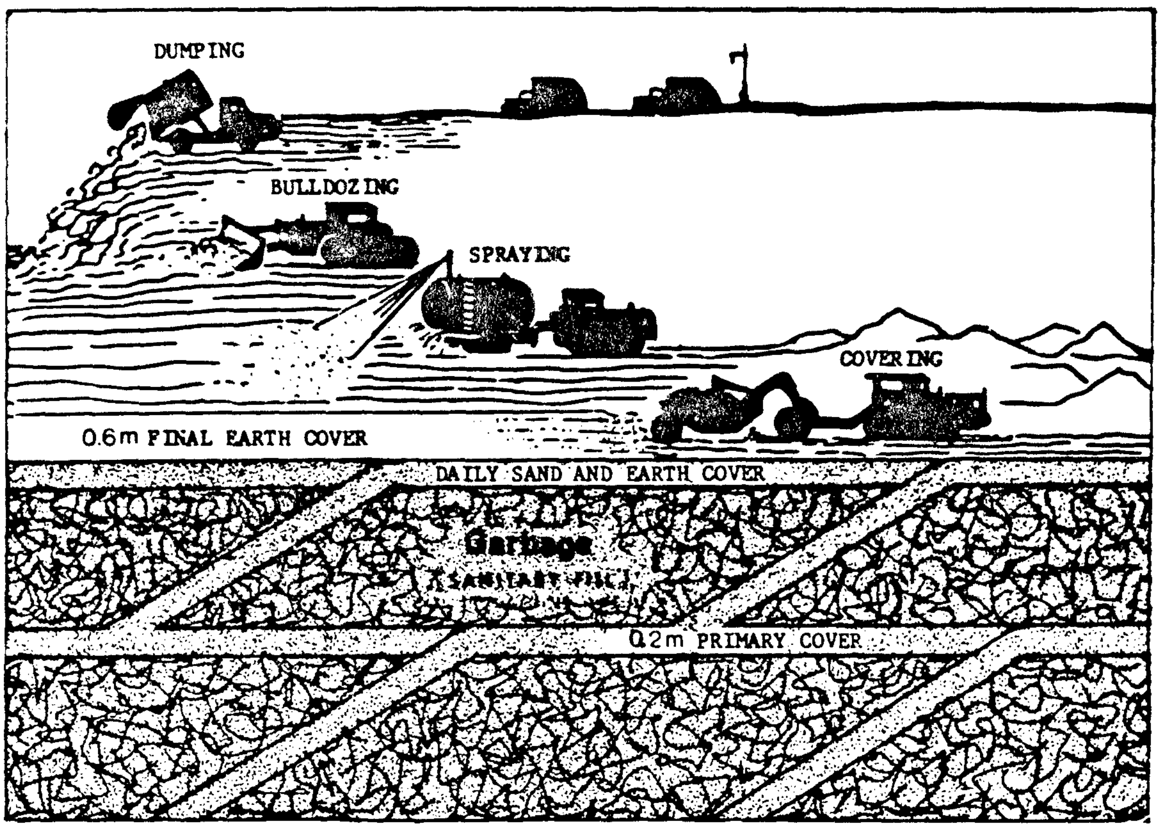

Figure 1. Schematic view of a landfill showing the various operations and arrangement of "garbage cells" underground

some reason, daily cover has not been placed on the exposed solid waste surface in the prescribed daily fashion. This may occur at some landfill sites because the supply of cover material is sometimes uncertain and not enough cover material is available to meet daily cover needs. Once the landfill has been filled to capacity, final cover material (0.6 to 1.5 m of material) is used to close the landfill. The upper portion of the cover (usually 0.3 to 0.6 m) must be able to support vegetation because the entire site is planted with grass and shrubs to improve aesthetics and to control erosion. Final cover also serves the function of limiting permeability (10^{-5} cm/sec) thereby controlling infiltration, percolation, and gas.

Dewatered dredged material can substitute for conventional landfill cover, which is required by law for daily, intermediate, and final cover on landfills in the NY/NJ Harbor area. At the present time the average cost for conventional landfill cover material is $3 to $4 per cubic meter. However, within the next 10 years, the cost of conventional cover may be as high as $10.50 per cubic meter according to a study by the New York City Department of Sanitation (3). Many landfills in the NY/NJ area are scheduled to close within the next few years and will require final cover material. The New York District developed a three-phase study of the use of dredged material as sanitary landfill cover with the Fresh Kills Landfill (NY) and the proposed DeKorte State Park (NJ) as case examples (Figure 2). In order to establish

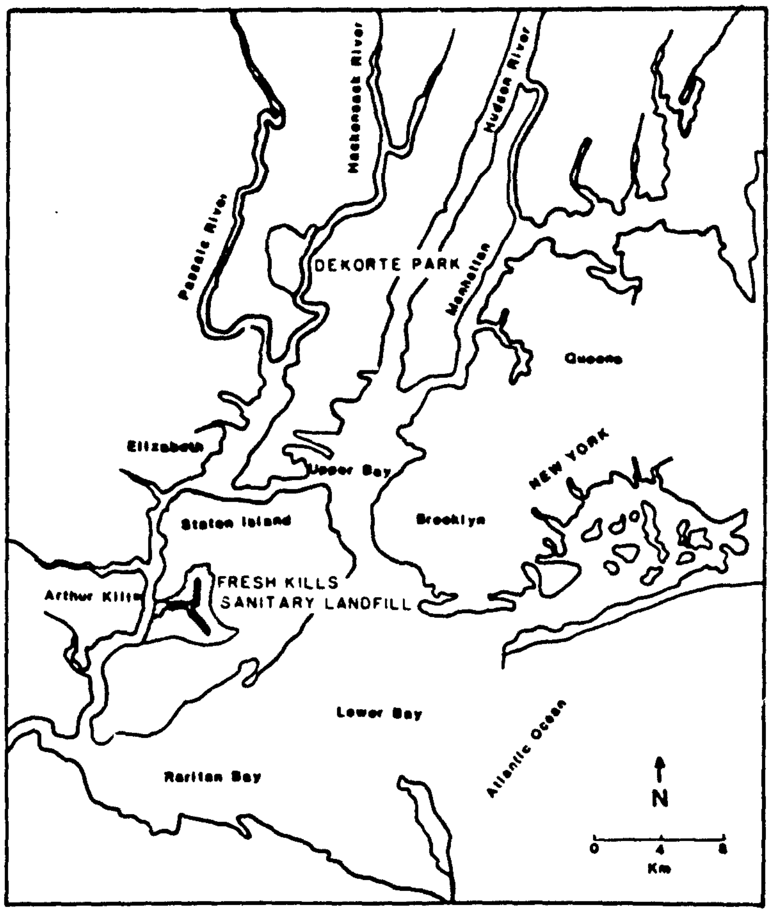

Figure 2. Location map of DeKorte Park and Fresh Kills sanitary landfills

regulatory criteria, the New York District asked the state environmental agencies for guidance concerning tests and regulations which would be applicable to dredged material to be used as sanitary landfill cover.

Phase 1 Report

The Phase 1 Report (4) indicated that the use of dredged material as sanitary landfill cover appeared to be feasible. Thirty-three typical dredged material samples were tested from all of the heavily dredged areas in the ha-bor including several that were unacceptable for unrestricted ocean disposal (Figure 3). The U. S. Army Corps of Engineers does not have jurisdiction over upland disposal of dredged material. Upland disposal is regulated by

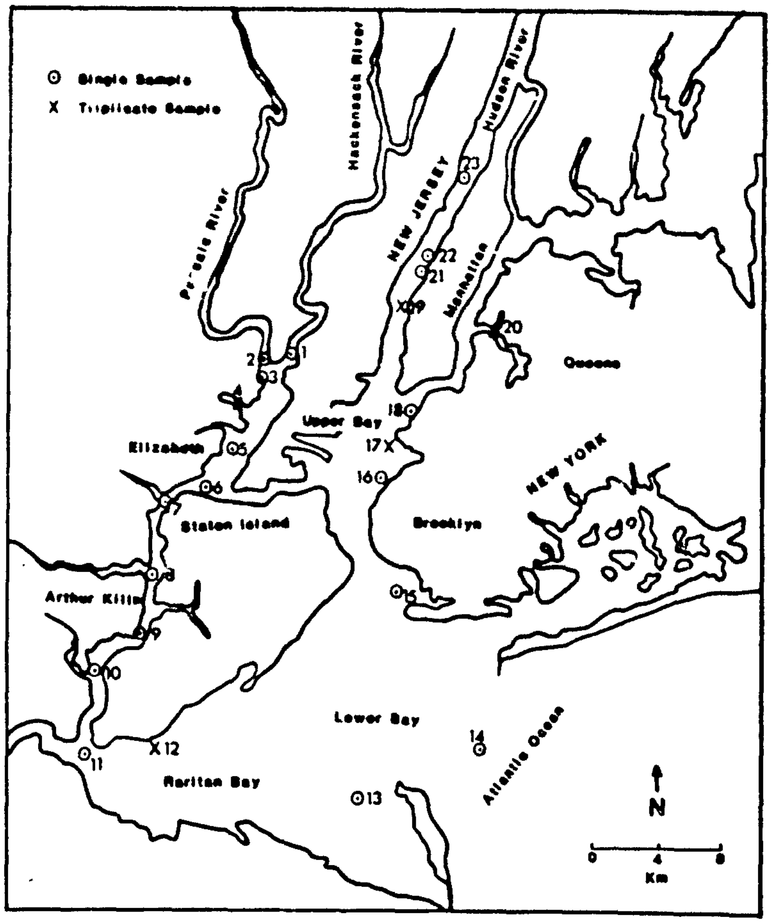

Figure 3. Sample locations of "typical" dredged material for use as sanitary landfill cover

state agencies. They determine the required testing criteria for upland disposal and use of dredged material as sanitary landfill cover. For the purposes of New York and New Jersey state criteria for testing dredged material for use as sanitary landfill cover, the Extraction Potential (EP) toxicity test was used to approximate the potential of leaching chemical constituents from dredged material and for comparison purposes with landfill leachates measured at the Fresh Kills and DeKorte State Park landfills.

The EP toxicity test (40 CFR 261.24) was developed by the U. S. Environmental Protection Agency (EPA) and is mandated under the Resource Conservation

Recovery Act (RCRA) for determining the identity and quantity of toxic waste materials by an acid extraction process. It is important to note that the intent of the test is to identify toxic waste materials so that they can be properly monitored and disposed in compliance with EPA regulations.

Hazardous wastes are defined under RCRA by a series of parameters including ignitability, corrosivity, reactivity, and toxicity. Designation as a toxic waste includes determination of the nature, quantity, and concentration of toxic materials; potential for migration; persistence of the toxic constituents; and degree of bioaccumulation exhibited. The EPA has not determined that the EP toxicity test is an appropriate test for dredged material. Dredged material does not exhibit the characteristics of toxic waste as defined by RCRA.

The application of the EP toxicity test was done to meet New York and New Jersey state criteria for use of dredged material as sanitary landfill cover. The U. S. Army Corps of Engineers agreed to perform EP toxicity tests on the 33 harbor-wide sediment samples in order to comply with the states' criteria for use of dredged material as sanitary landfill cover.

All of the 33 samples tested for EP toxicity from the NY/NJ Harbor area were near or below detection limits for the test (Table 1). As discussed

TABLE 1. EP TOXICITY DATA: RANGE OF CONCENTRATIONS OF CONTAMINANTS IN 33 SEDIMENT SAMPLES (Ref. 4)

Constituent	Range of 33 values mg/ℓ	Mean mg/ℓ	Maximum Allowable Concentration, mg/ℓ
Arsenic	<0.05	<0.05	5.0
Barium	<0.3	<0.3	100.0
Cadmium	<0.01-0.07	0.02	1.0
Chromium	<0.05	<0.05	5.0
Lead	<0.1	<0.1	5.0
Mercury	<0.005-0.004	0.007	0.2
Selenium	<0.05	<0.05	1.0
Silver	<0.02	<0.02	5.0
Endrin	<0.01	<0.01	0.02
Lindane	<0.01	<0.01	0.1
Methoxychlor	<0.1	<0.1	10.0
Toxaphene	<0.1	<0.1	0.5
2,4-D	<1.0	<1.0	10.0
2,3,5 TP	<1.0	<1.0	1.0
PCB's	<0.01	<0.01	*
Chlorides	125-489	298.45	*

* No established RCRA limits.

earlier in this paper, only 2 to 5 percent of the annual volume of maintenance dredged material is unacceptable for unrestricted ocean disposal in the Port

of NY/NJ. Although this 2 to 5 percent does contain some contaminants as would be anticipated in an industrial port area, none of the dredged material in the NY/NJ Harbor area could be considered to be toxic material or hazardous waste.

Change in pH over time was measured to monitor the acid-generating potential of the dredged material. It was determined that acid toxicity would not occur to vegetative grown in any of the dredged material tested. The PCB levels were less than the 0.01-mg/ℓ detection limit in all samples.

Approximately 70 percent of the annual volume of fine-grained dredged material meets the vegetative support requirements and can be used as final cover. All of the dredged material tested met the criteria for daily and intermediate cover. This represents 2 million cubic meters of dewatered dredged material which could meet 40 percent of the annual demand of the 19 NY/NJ landfills (assuming 7.5 million cubic meters dredged material annually).

The New York State chemical testing requirements and functional requirements for odor, litter, fire, and leachate control were met by all of the dredged material samples.

<u>Phase II Draft Report</u>

The Phase II Draft Report (5) gives further indication that the use of dredged material as sanitary landfill cover is technically feasible. The cost for dewatered dredged material using regional dewatering sites within 10 miles of the Fresh Kills landfill and DeKorte State Park landfill are considerably higher than for dewatering onsite at the landfills.

The report investigated various dewatering alternatives: surface drainage, underdrainage, optimum thin lift, surface trenching, progressive trenching, filling, and crust management. Optimum thin lift is defined as the amount of dredged material which can be dewatered in a year's time within a particular climatic regime and was studied by the U. S. Army Corps of Engineers Waterways Experiment Station (WES) (6). Optimum thin lift (spreading wet material in a 0.52-m-thick layer) plus surface trenching would yield approximately 2,140 cu m of dewatered dredged material per hectare per year. Very thick lifts and extensive crust management would yield 4,586 cu m per hectare per year. The cost of dewatered dredged material from the regional dewatering sites studied ranged from $12.95 to $20.60 per cubic meter (Table 2). A large site near a navigable waterway is the most cost-effective for a regional dewatering site.

The draft report suggested ways in which the costs could be reduced including reducing or eliminating land costs and reducing unloading costs by using two dredges simultaneously. Having the dredgers pay the transport cost to the dewatering site would reduce costs to the landfill operator.

Comparison of leachate from the landfills with the EP toxicity tests for the dredged material samples indicates that pollution levels in water leaching from dredged material would be several orders of magnitude lower than leachate from the DeKorte State Park and Fresh Kills landfills. PCB retesting (acid extraction) showed that all of the samples were below the detection limit of 0.01 mg/ℓ (which is 100 times the New York State drinking standard).

TABLE 2. ESTIMATED COST PER CUBIC METER OF DEWATERED DREDGED MATERIAL DELIVERED TO THE LANDFILL STOCKPILE FROM DEWATERING SITES A, B, C, D

	To Fresh Kills Landfill		To DeKorte State Park	
Cost Factor	Site A 161 Hectares	Site B 32 Hectares	Site C 202 Hectares	Site D 59 Hectares
Transport to site	$3.66	$3.13	$3.66	$3.13
Site development	0	4.05	0	6.27
Site work	0.13	0.52	0.26	0.26
Crust work	0.32	1.04	0.39	0.52
Mobilization/ demobilization	0.39	1.70	0.26	0.91
Unloading	3.92	3.92	3.92	3.92
Subtotal	$8.42	$14.36	$8.49	$15.01
Land lease (10 percent of market value per year)	$ 1.83	$ 1.83	$ 7.05	$ 1.83
Subtotal	$10.25	$16.19	$15.54	$16.84
Haul to landfill	6.67	6.27	6.54	10.07
Total	$16.92	$22.46	$22.08	$26.91

NOTE: The present cost of cover is $3 to $4 per cubic meter.

Phase III

The New York District will continue the feasibility study of the use of dredged material as sanitary landfill cover. Phase III will consist of:

a. Sampling and chemical testing of dredged material in accordance with New Jersey Department of Environmental Protection Criteria.

b. A thorough economic analysis of regional dewatering, including all 19 landfills in the NY/NJ Harbor area and any upland sites under consideration as disposal sites.

c. A feasibility study using a site in New Jersey as a source of dredged material which is presently in a dewatered state for use as landfill cover. This site was used for disposal of dredged material from the Raritan River until 5 years ago. It was extensively studied by WES as part of the Dredged Material Research Program (DMRP) (7). If

permission is granted by the owner, the site could be excavated and later refilled with dredged material.

d. The feasibility of direct hydraulic or mechanical emplacement of dredged material will also be studied at DeKorte State Park. A total of 4.6 million cubic meters of dewatered material is needed for landfill closure to create the park.

e. A literature search will be performed with regard to the viability of pathogens in upland disposed and dewatered dredged material.

If the use of dredged material as sanitary landfill cover proves economically feasible, dredged material may be used as a resource material. At present the clean sand dredged from the Port of NY/NJ is used as a resource material for beach nourishment and for capping. In much the same way, the finer grained portion of dredged material may become a desirable resource for use as sanitary landfill cover and become an integral part in the management of dredged material in the NY/NJ Harbor area.

Regional dewatering sites for use of dredged material as sanitary landfill cover could be established at the upland sites which are also being studied as part of the Dredged Material Disposal Management Program. Dewatering sites could also be developed at some of the containment area and island sites which have been studied by the New York District.

UPLAND DISPOSAL

Upland disposal of dredged material is a commonly accepted practice in the United States and the rest of the world. In the New York District, upland disposal currently is limited to small Federal, state, and private channels and slips. Disposal usually takes place at adjacent sites. The present investigation differs from past practices in that it attempts to locate one or more sites which could serve as regional upland disposal sites for dredged material from the Port of NY/NJ.

Dredging and disposal technology and upland disposal site design are both well established. The primary obstacles to the use of this option for the Port of NY/NJ are the limited availability and high cost of large tracts of open land in the greater New York area. The primary task for the New York District was to locate available land which could be used as environmentally and economically sound upland disposal sites for dredged material.

A report prepared for the New York District (8) identified and classified existing undeveloped, vacant land within a 160-km radius of New York Harbor. This was done utilizing land-use maps generated from LANDSAT satellite imagery of the region. Three categories of vacant land were identified: crop and pastureland, wetlands, and barren areas.

In order to develop some means to eliminate unsuitable areas from consideration, we asked the environmental regulatory agencies of the States of New York and New Jersey to list criteria that would determine the suitability of upland sites for the disposal of dredged material in their respective states. Based upon early responses from these state agencies it was determined that crop and pastureland and wetlands were very valuable and would not

be considered further. This limited further investigations to the 295 barren areas (land with less than one third vegetative or other cover) which ranged in size from 4 to 1300 ha.

A preliminary evaluation of these barren areas summarized the most important factors about each site such as soil type and adjacent land use (9). The report described cultural features, physical features, and accurate geographic location, and contained detailed maps and aerial photographs of each site.

With the input from the state regulatory agencies, the New York District developed screening criteria for upland disposal siting. Sites were eliminated if they were:

a. Located on predominantly agricultural soil (10, 11, 12, 13).

b. On or adjacent to a major soil source aquifer, in a reservoir drainage area, or within 1.5 km of any water supply well (14, 15, 16, 17).

c. Within designated significant wildlife areas (18).

d. Located in drainage areas of high quality water such as trout streams (19, 20).

e. Located on easily soluble bedrock (such as limestone) or porous sand and gravel (21, 22).

f. Built upon since the earlier screening took place (based on 1980 aerial photographs and site visits).

g. Located in state or Federal parklands or recreation areas (16).

h. Within 150 m of residential areas. Portions of the site beyond the 150-m buffer strip were not eliminated.

i. Adjacent to coastal erosion hazard areas (for New York State).

In addition, the following information about the sites was noted:

j. Flood-prone areas and coastal flood hazard areas (23).

k. Local zoning and site ownership.

l. Distance from the nearest navigable waterway and elevation of the site (16).

Item number l will help determine the cost of transporting dredged material to the site. It would not be practical to pump dredged material from several dredging sites directly to a regional disposal site because dredging needs are widely dispersed throughout the Port of NY/NJ. Since most dredging in the New York Harbor region is performed by mechanical means (clamshell dredging), the most likely scenario would be transporting the dredged material

by scow to a shore transfer facility near the regional disposal site where the material can be hydraulically pumped into the disposal site. If the hydraulic pipeline requires more than one booster pump to deliver the dredged material from the shore transfer facility to the disposal site, each additional booster station would cost over $1 million to build and $67,000 per year to operate. The next least expensive method to deliver the dredged material to the disposal site would be truck haul an this is approximately three times more expensive than pipeline transport (24). Due to the costs involved, the New York District concluded that a site which is more than 8 km from a navigable waterway (the distance which corresponds to a hydraulic pipeline with one booster pump) should only be considered for receiving dredged material which is not suitable for disposal using less expensive disposal alternatives. Sites which are less than 8 km from a navigable waterway can be considered for disposal of any dredged material.

After the screening process took place, the New York District was considering approximately 56 remaining sites in each state. The state regulatory agencies again reviewed information about these sites, and, as a final check, the New York District performed site visits. Based upon this information, several more sites were eliminated. At the present time the New York District is considering 13 sites which might be suitable for development as regional upland disposal sites for dredged material (Figure 4). They range in size from 7 ha to 730 ha. Three are located more than 8 km from a shore facility and will only be considered for dredged material which is not suitable for disposal using less expensive disposal alternatives. A report describing the project has recently been released to state and local governments, Federal congressmen, and owners of sites and adjacent landowners in the subject areas who were all asked to supply the New York District with any pertinent information about the sites. Landowners were asked if they wish to sell, lease, or allow the use of their property. Public forums were held the first week of November 1983 in the subject areas.

After local coordination has been accomplished, the New York District will then perform detailed environmental and economic studies on the remaining sites. Final siting should be completed by early 1985.

CONTAINMENT AREAS AND ISLANDS

The containment areas and island option consists of the filling of diked areas with dredged material to form artificial islands or areas. The areas are attached to land on one or more sides to form peninsulas or to fill in coves. This is accomplished by disposing of dredged material within the diked area. At the present time, this option is not considered economically feasible in the unprotected waters of the open ocean off the coast of New York and New Jersey (25). Construction of containment areas and islands is considered feasible in protected shallow waters (26).

Containment areas and islands are of particular importance because they represent one of the new alternatives to ocean disposal which may accommodate "questionable" dredged material. The engineering and design feasibility of containment facilities (areas and islands) has been well established through comprehensive studies by WES as part of the DMRP. Containment areas and islands have been successfully used throughout the United States. For

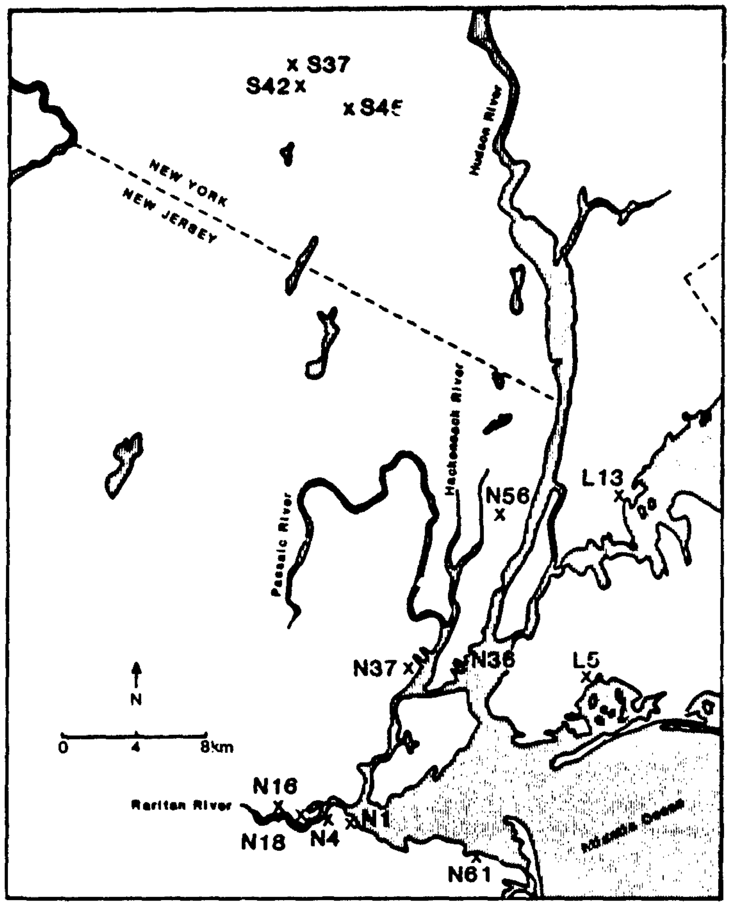

Figure 4. Sites proposed for further study in October 1983

example, the Craney Island, Virginia, containment facility has been in operation for more than 35 years.

This alternative shows potential for the full range of dredged material: from material that is acceptable for unrestricted ocean disposal to material which is unacceptable for ocean disposal ("questionable" material).

Uses of Containment Facilities

Containment areas and islands which have been constructed throughout the United States have been dewatered over a period of 10 to 20 or more years to form solid land. The land has been used for recreational areas, bird sanctuaries and nesting areas, and light industrial areas, among other uses. However, the facilities could also be used as a materials rehandling center (i.e. to separate sand for construction purposes from other grain sizes of dredged material), or for dewatering areas for use of dredged material as sanitary landfill cover.

Containment areas and islands are constructed in an environmentally sound manner so that dredged material, including "questionable" dredged material, is

isolated from the environment. An impermeable liner (of plastic or clay) would be emplaced to prevent possible contamination due to leaching, and a weir system controls the rate and composition of effluent returning to the waterway.

Containment facilities are usually divided by several internal dikes to promote efficient dewatering. They can be divided into cells to separate acceptable dredged material from "questionable" dredged material. Ideally, several containment facilities could be located throughout NY/NJ Harbor area. The availability of containment facilities on several reaches within the NY/NJ Harbor area would minimize transportation costs because the material would be dredged from projects in close proximity to each facility. This would eliminate the added transport costs of disposing of dredged material at the "Mud Dump" site where 90 percent of all NY/NJ dredged material is currently disposed. In addition, dredging costs may be lowered because hydraulic dredging, which is more economical for dredging material and emplacing it within a short distance, could be used in place of clamshell dredging. Clamshell dredging with subsequent barging of dredged material to a disposal site is more expensive than hydraulic dredging, but allows the material to be transported greater distances than is possible with hydraulic dredging. Clamshell dredging is the method which is used for most of the volume of maintenance dredging in the NY/NJ Harbor at the present time.

Preliminary siting for containment areas and islands was done with the help of the U. S. Fish and Wildlife Service (27). Their report defined areas of high biological productivity which were then dropped from further consideration. The report also prioritized areas for further investigation and recommended that siting of a large containment island (greater than 400 ha) be limited to the Lower Bay of New York Harbor. The New York District incorporated the results of the report into their siting criteria and began secondary siting for containment areas and for wetlands stabilization areas (disposal of dredged material which is stabilized by planting marsh vegetation to form wetlands). Siting criteria were developed to narrow down the areas for further study by the application of appropriate regulatory, economic, and environmental considerations.

A thorough field investigation of the NY/NJ Harbor area was conducted by the WES and the New York District. Using the criteria presented in Table 3, and criteria specific to the viability of wetlands vegetation, nine sites were identified for wetlands stabilization (28) (Figure 5). The WES report recommended that five sites be used concurrently because they represent a good geographical spread of locations. These sites were ranked according to relative cost of construction (dike length/volume ratio) and distance of hauling or pumping from heavily dredged reaches.

After evaluating the criteria (Table 3) the Corps decided that the siting criteria for containment areas and islands were very similar to that for wetlands stabilization and that the confined sites defined in the WES report would also be suitable for containment areas.

The costs shown in Table 4 are the minimum costs for containment facility construction and assume availability of suitable onsite material for dike construction. Actual dike costs and total construction costs of containment

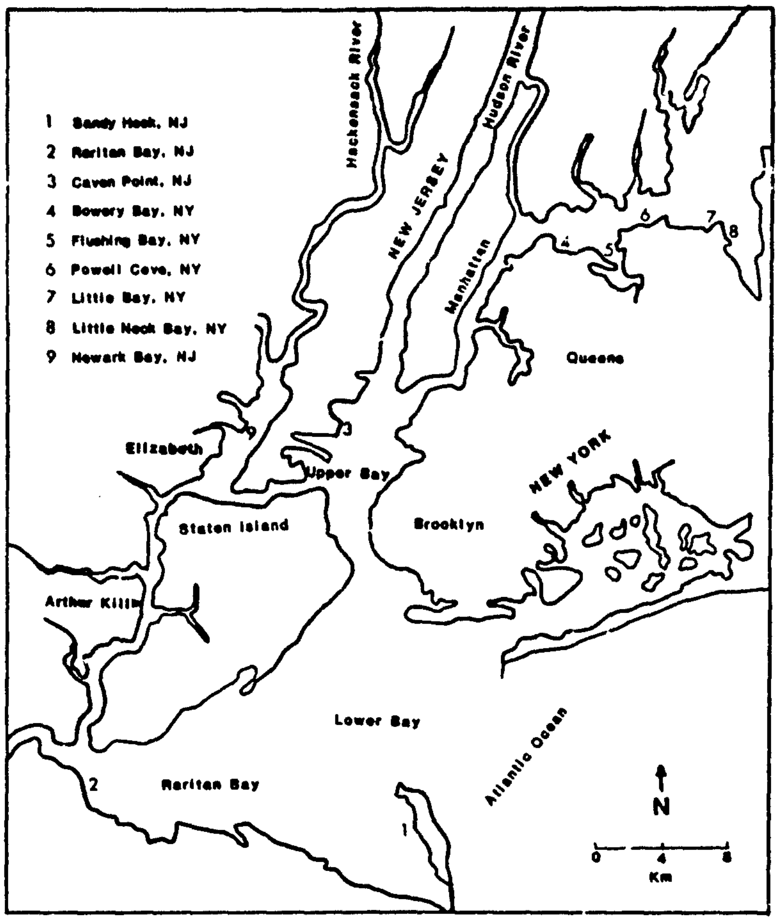

Figure 5. Wetland stabilization and containment area sites

areas and islands are likely to be considerably higher than those listed. An estimate of construction costs for an 80-ha containment site using sand, rock, and steel dikes with materials brought from off the site is $40 million.

A containment facility designed to hold only "questionable" material may be suitable for one of the sites such as the Newark Bay site. This would provide a disposal facility for maintenance and private dredging from this highly industrialized bay.

Remaining Containment
Facility Sites, NY/NJ Harbor

Several sites were dropped from further consideration due to comments received from the Steering Committee. The sites which remain to be studied are: Raritan Bay (Sayreville and South Amboy, N. J.), Bowery Bay (Upper East River, N. Y.), Flushing Bay-North (Upper East River, N. Y.), and Newark Bay (Port Newark, N. J.). Their final use (wetlands versus containment areas) has not yet been determined.

TABLE 3. SITING CRITERIA FOR CONTAINMENT AREAS AND ISLANDS IN THE NY/NJ HARBOR AREA

Prohibited from areas of high biological productivity
Prohibited from navigation channels
Prohibited from recreational beaches
Minimum capacity 230,000 cu m
Minimum capacity for large containment island 76,450,000 cu m
Containment areas attached on one or more sides to land
Accept full range of dredged material including "questionable" dredged material
Prohibited from areas inaccessible to navigation
Prohibited from restricted military zones
Prohibited from active fault zones
Avoid anchorage areas
Avoid incompatible uses in the public interest (navigation and port projects)
Avoid major extension and relocation of sewer lines (cost = $6,000/linear meter on a major line)
Buy-out of users of the waterway must be cost-effective
Site protected from wave energy:
- Minimize fetch (distance over which the wind travels to create waves)
- Shoreline configuration should be a cove or meandering shoreline
- Grain size in swash zone between 0.4 and 0.8 mm

Tidal range: 1.8 m maximum
Wetlands exist nearby (preferred)
Minimize construction cost by comparing dike length to containment volume ratio for sites (small dike length to volume ratio preferred)
Hauling distance from dredging site should be minimized (should be close to heavily dredged sites)
Good geographic coverage of harbor area preferred (multiple sites located on separate reaches preferred)

The New Jersey Department of Environmental Protection (NJDEP) suggested that the Newark Bay site become a containment area for dredged material which is not acceptable for unrestricted open water disposal and possibly a dewatering site for use of dredged material as sanitary landfill cover. The use of Bowery Bay and Flushing Bay which flank LaGuardia Airport for wetlands stabilization was objected to due to potential problems with bird populations. None of the agencies objected to the use of Bowery Bay. The Raritan Bay site could be used for either wetlands stabilization or a containment area, but would need to be compatible with development plans for the area.

TABLE 4. COST AND CAPACITY FOR CONTAINMENT AREA AND ISLAND SITES IN THE NY/NJ HARBOR AREA

Site Location (from WES Siting Report)	Average Water Depth at Mean Low Water (mlw), m	Total Cost of Containment Area (Dike 3 m above (mlw)*	Cubic Meters (Calculated)	Total Construction Cost Per Cubic Meter (with 3-m dike)
1. Sandy Hook Bay**				
2. Raritan Bay	0.9	$2,662,745	5,035,491	$0.53
3. Caven Point	0.9	$3,193,572	7,660,431	$0.42
4. Bowery Bay	3.6	$1,018,177	3,460,457	$0.29
5. Flushing Bay	A 1.8 B 1.5	$ 929,045 $ 461,072	1,684,028 603,548	$0.55 $0.76
6. Powell Cove	0.9	$1,208,888	2,785,611	$0.43
7. Little Bay	2.7	$1,620,258	5,022,541	$0.32
8. Little Neck Bay	0.9	$ 752,984	1,555,300	$0.48
9. Newark Bay	0.5	$1,944,578	2,485,284	$0.78

Note: Total surface area for all potential containment areas = 1,435 ha.
Total volume for all potential 3-m dike containment areas = 30,292,691 cu m.

* Containment area dike height (3 m above mlw) equals average water depth at mean low water plus 2.5-m fill height plus 0.6-m freeboard. The volumes do not take into account compaction (either natural or mechanical) of the dredged material which could double the capacity. Weir cost = $10,000, plastic liner = $1.30/sq m, dike composed of onsite material + 30% for contingencies.

** Sandy Hook Site is for unconfined disposal/wetlands stabilization only.

Final Siting

Public forums will be held in the local areas to gain additional public comments to the sites. The use of the sites for either containment areas or wetlands stabilization will then be determined.

One year of physical and biological sampling and monitoring of the sites will be performed. This study will include site-specific physical and engineering properties of the sediment, subsurface geology, hydrology, and characterization of benthos, fish, and wildlife. The Waterways Experiment Station will provide site-specific dike and/or containment facility design.

Final siting of containment areas will be coordinated with Federal, state, and local governments; community boards; and local residents. The New York District will analyze the final siting data and produce a Position Paper on the feasibility and acceptability of containment areas and islands.

The Large Containment Islands Concept

The Large Containment Islands concept was studied separately and concurrently with smaller containment areas and islands. Large containment islands siting studies by the New York District consisted of the feasibility of siting one or more containment islands, 400 or more hectares in size, in the NY/NJ Harbor area. Large containment islands are constructed by placing dredged material in diked areas over a period of time (usually 10 to 20 years), dewatering the dredged material, and forming solid land which can be used productively.

As discussed in the section on containment areas and islands above, the large containment islands concept is restricted to siting in shallow, protected waters. This option was considered to be "possible in special cases," but was singled out by an intergovernmental regulatory agency Steering Committee for special consideration because it is one of the few options which could prove feasible for disposal of "questionable" dredged material (material which is not suitable for unrestricted ocean disposal). Other potential advantages of siting large containment islands include disposal of 20 or more years of maintenance dredged material from the NY/NJ Harbor area and decreased transport costs from most reaches to a centrally located site within the harbor area rather than to the "Mud Dump" site for ocean disposal.

The engineering and economic aspects of construction of large containment islands have been extensively studied by WES in the DMRP together with methods for confining and dewatering dredged material in an environmentally acceptable way. The results of the studies have been applied to construction of large containment facilities by the Corps throughout the United States. Recently, the Corps constructed the Hart-Miller Island (Baltimore, Maryland) containment facility in cooperation with the state. This facility is a multiuse area which has docking facilities and recreational beaches fringing the dikes and incorporates two former artificial islands. It is expected to become a recreational area once the site is filled and the dredged material is dewatered.

Preliminary siting of large containment inlands by the U. S. Fish and Wildlife Service, using criteria developed by the New York District, limited further siting to the Lower Bay of New York Harbor (27). The limitation was done on the basis of size and environmental impact because the Lower Bay is the only protected shallow-water area in the NY/NJ Harbor area which could accommodate one or more 400-ha (or larger) islands. In other areas the size of the island would cause deleterious impacts on water circulation and cause severe environmental impacts.

A report on large containment islands in Lower Bay, New York Harbor, was prepared (30). The report reviewed previous large island proposals that had been sited in the Lower Bay, but had not been built, and discussed the environmental engineering and economic concerns of siting large containment islands in the NY/NJ Harbor area. Although the large containment island concept has many positive attributes, as described above, several limiting factors led the New York District to conclude that the large containment area option is not feasible at the present time and should be dropped from further consideration in the Management Plan (31). The New York District Position Paper on Large Containment Islands noted that the location and configuration of a 400-ha or larger island would be restricted to the West Bank of the Lower Bay. Model studies by WES in conjunction with a siting study for a containment island which would have enclosed Hoffman and Swinburne Islands (artificial islands made partly of dredged material) indicate that a teardrop-shaped configuration of 690 ha including both islands would cause the least disturbance to circulation patterns in the Lower Bay (32). The National Park Service objects to present use of these islands as part of a containment island because they have other plans for the man-made islands as part of Gateway National Recreation Area. The cost of construction of a large containment island per cubic meter of capacity is two to three and a half times that of ocean disposal. Serious land-use issues, final use, and ownership of the island(s) would need to be resolved. Moreover, the ecological value of at least 400 ha of bay bottom which would be irretrievably lost if a containment island were constructed in that particular location is at issue (31).

The Position Paper on Large Containment Islands was sent to the Steering Committee and Vice Chairpersons Group of the Public Involvement Coordination Group for review. The comments received so far indicate that the U. S. Fish and Wildlife Service agrees with the New York District's position that the option be dropped from further consideration until the issue of the value of the bay bottom can be resolved. The State of New York Coastal Management Program would like the option to be considered further and suggested that synoptic fisheries studies be conducted in the Lower Bay in order to determine whether there are areas of lower productivity which could be acceptable for large containment areas. Such an assessment is currently under way by the National Marine Fisheries Service. Additional comments are anticipated from the other members of the Steering Committee. Once these are received, a decision on continuance or discontinuance of studying the large containment island option will be forthcoming.

Sport fishermen's groups have delayed a smaller demonstration project (filling of a small part of a subaqueous borrow bit in the Lower Bay) through litigation due to environmental concerns. The project would have covered

19 ha of bay bottom and would have contained only material acceptable for unrestricted ocean disposal. A large containment island would be used for disposal of the full range of dredged material, including material which is unacceptable for unrestricted ocean disposal and would be more than 20 times the size of the borrow pit demonstration project. In addition, many areas in the Lower Bay are known to be highly biologically productive and support a sizable sports fishing and commercial fishing industry. Siting a large containment island in an area which is considered to be productive by fishermen's groups would seem unlikely, judging from previous experience with the borrow pit project.

Several of the large containment islands which have been previously proposed for study and/or implementation are shown in Figure 6. Of these, the site proposed by the NJDEP is in the least desirable location because, although it is situated near heavily dredged reaches, model studies have shown that circulation would be greatly disrupted.

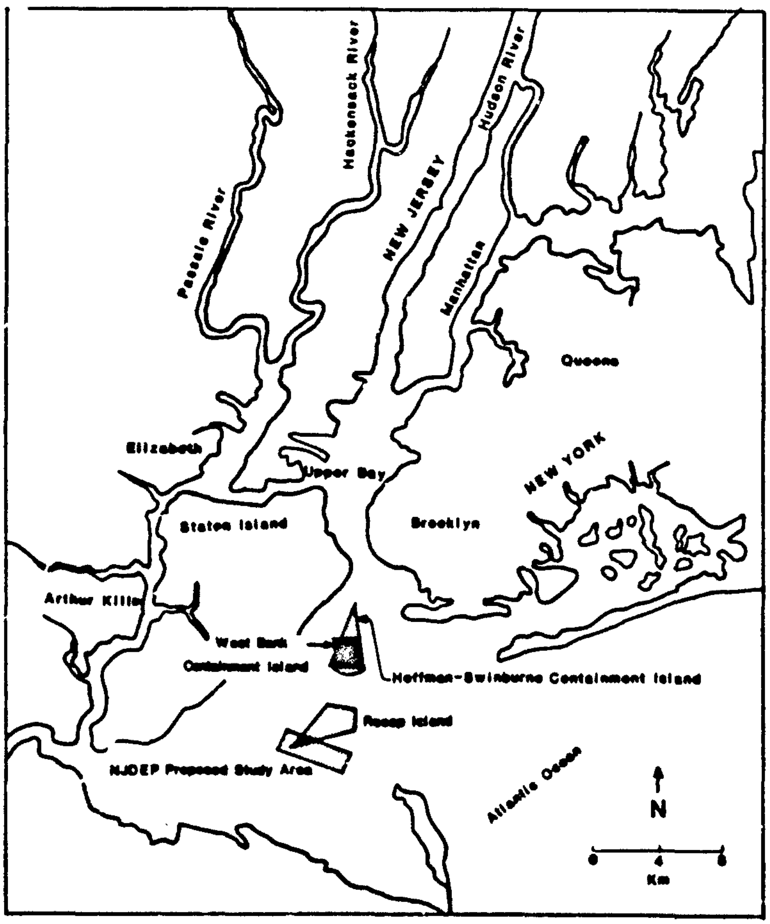

Figure 6. Locations of previously proposed containment islands and study areas

CONCLUSIONS

The dredged material disposal alternatives discussed in this report appear to be technically feasible. These three options are potentially applicable to 2 to 5 percent of the 6 to 7.5 million cubic meters dredged annually from the Port of New York and New Jersey.

The feasibility studies for the sanitary landfill cover option have resulted in the development of siting criteria and regulations concerning use of this option. Dredged material may provide a valuable source of cover for landfills in the NY/NJ Port area provided that it proves to be economically feasible. Upland disposal siting has located 13 potential upland disposal sites. Some of these could be used as dewatering sites for use of dredged material as sanitary landfill cover. Siting of containment areas and islands is under study in four areas of the port region. Containment areas and islands could be used as dewatering and rehandling sites for use of dredged material as sanitary landfill cover or developed after being filled as parklands or industrial areas. The large containment island concept has been recommended to be dropped from further consideration at the present time by the New York District due to several factors, especially the difficulty of locating an environmentally acceptable area and the cost (two to three and a half times the cost of ocean disposal).

All three disposal options appear to be technically feasible. However, the major obstacle in implementing any of these options appears to be public acceptance rather than technical issues.

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REHABILITATION OF ESTUARIES IN TSU-MATSUSAKA HARBOR

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INTRODUCTION

This paper continues discussion of the pollution control project in Tsu-Matsusaka Harbor. Discussion of the project began at the 6th U.S./Japan Experts Meeting; at that time dredging had not begun. To improve the harbor's water quality, it was necessary to remove the polluted sediments from the Shitomo and Iwata Rivers flowing into the harbor. At present, dredging of the Shitomo River is complete and dredging of the Iwata River is continuing.

BACKGROUND

Mie Prefecture is situated approximately in the center of Honshu Island and faces Ise Bay (Figure 1). It has an area of 5,760 km^2 and a population of 1,720,000. The coast has a total length of 1,080 km with two major harbors, Yokkaichi and Tsu-Matsusaka, and 17 local ports.

Tsu-Matsusaka Harbor lies in the center of the southern half of the Ise Bay Coast. This harbor has a coastal length of 30 km extending from Tsu City in the north to Matsusaka City in the south and has a harbor area of 61 km^2.

In 1971 the two regions, Tsu and Matsusaka, were consolidated into one major harbor. As a base of inland marine transport, coastal industries,

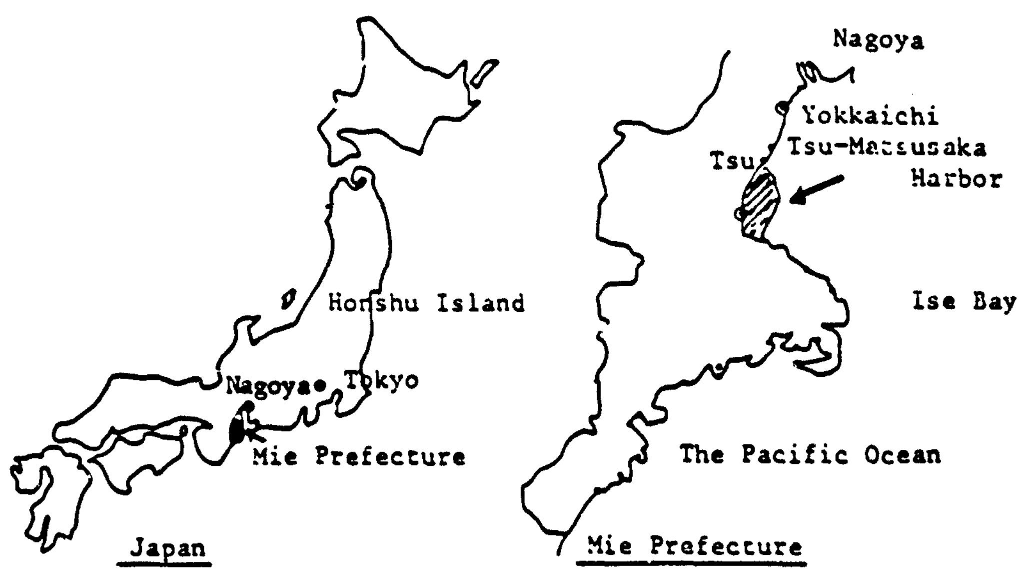
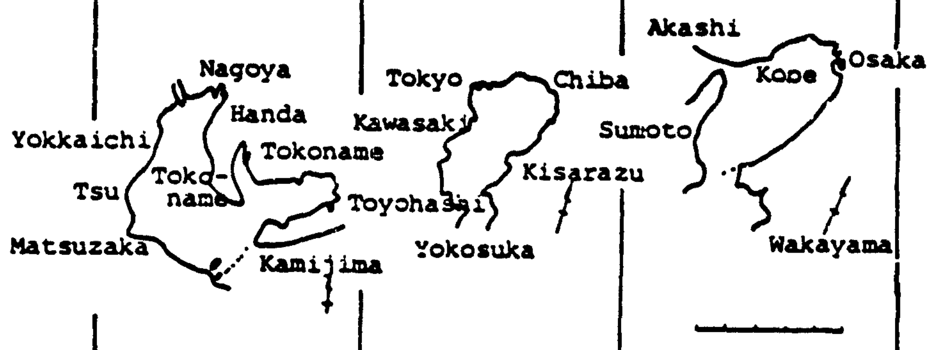


Figure 1. Location of Tsu-Matsusaka Harbor

marine recreation, and fishery, the port handled goods in the amount of 1,478,000 tons in 1981.

Ise Bay has surface area of 1,620 km^2 and a coastal length of 290 km. It is larger than Tokyo Bay and Osaka Bay as shown in Figure 2 and has a water depth of less than 15 m in most parts (50 percent).



	Ise Bay	Tokyo Bay	Osaka Bay
Coastal Length	290 km	154 km	160 km
Water Area	2,130 km^2	1,160 km^2	1,400 km^2
Water Depth			
- 15 m	1,000 km^2	560 km^2	390 km^2
- 10 m	620 km^2	360 km^2	140 km^2
- 5 m	290 km^2	180 km^2	35 km^2

Figure 2. Comparison of Japan's three largest bays

Since 1960, the rapid progress of the Japanese economy has caused environmental problems notwithstanding the elevated living conditions. In Yokkaichi, asthmatic patients took legal action concerning the serious air pollution problems.

For water pollution, the prefecture government is making an effort to reduce the quantities of pollutants flowing into the Bay. In Tsu-Matsusaka Harbor, the problem of cleaning up the Shitomo and Iwata Rivers has been investigated.

SEDIMENT

Survey

Water pollution of Ise Bay deteriorates the shoreline environment. The accumulated sediment and red tides in the bay cause foul odors. The red tide causes decreases in marine products and a decline in tourism.

To study this problem, a sediment survey was conducted within the Shitomo and Iwata Rivers in 1978 and 1979. These two rivers flow into the harbor and are believed to be the source of the sediments which cause the foul odor.

The sediments of the Shitomo and Iwata Rivers have a black color and a strong hydrogen sulfide odor. Water content of the Shitomo River is 194 percent, liquid limit is 121 percent, and plastic limit is 43.6 percent.

The grain size composition of sediment in the Shitomo River is 3.8 percent sand, 71.2 percent silt, and 25 percent clay.

The pollution indexes COD_{MN}, ignition loss (I.L.), and sulfide content are shown in Figure 3 according to sediment depth.

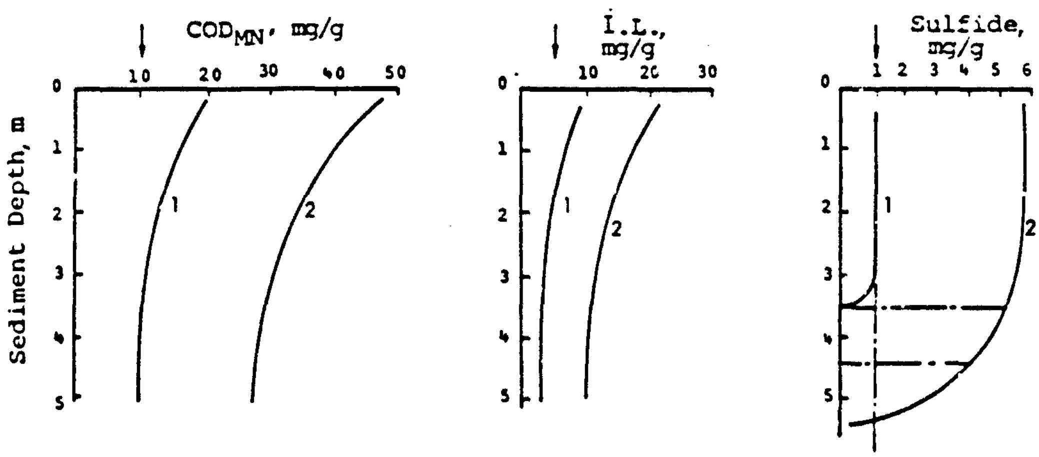


Figure 3. Pollutant concentrations in sediment; Curve No. 1 represents upstream and Curve No. 2 represents downstream

The sediment at Iwata River has a thinner thickness (3 m) than that of Shitomo River (4 m). The silty and clayish portion of the sediment is more than 80 percent, water content is less than 200 percent, and ignition loss is less than 10 percent. However, concentration of COD is comparatively high.

Removal Criteria

There are no official guidelines in Japan establishing polluted sediment removal criteria. For this study we used the following criteria for removal: COD_{MN} = 10 mg/g, ignition loss = 5 percent, and sulfide content = 1 mg/g. The limit concentration for sulfide was considered an important factor in eliminating foul odors.

Thickness to be Dredged

By considering the vertical distributions of COD_{MN}, ignition loss, and sulfide, the sediment thickness to be dredged was determined. Of these three indexes, the limit/concentration of sulfide (1 mg/g) was the most important. The thicknesses of sediment which indicate sulfide concentrations of more than

1 mg/g are shown in Figure 4. Figure 5 shows the vertical distribution of the sulfide.

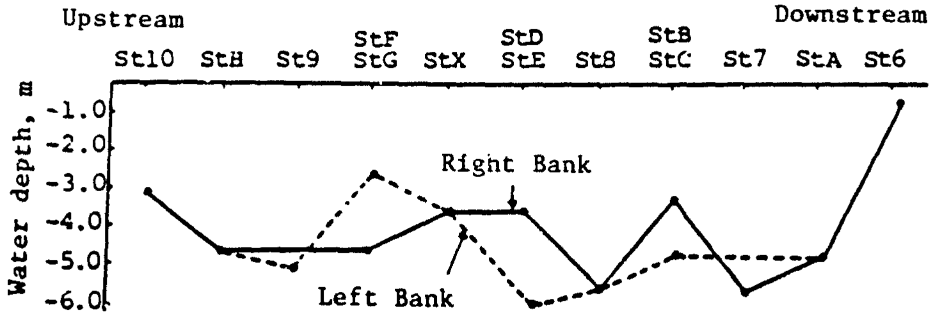


Figure 4. Dredged depth in Shitomo River

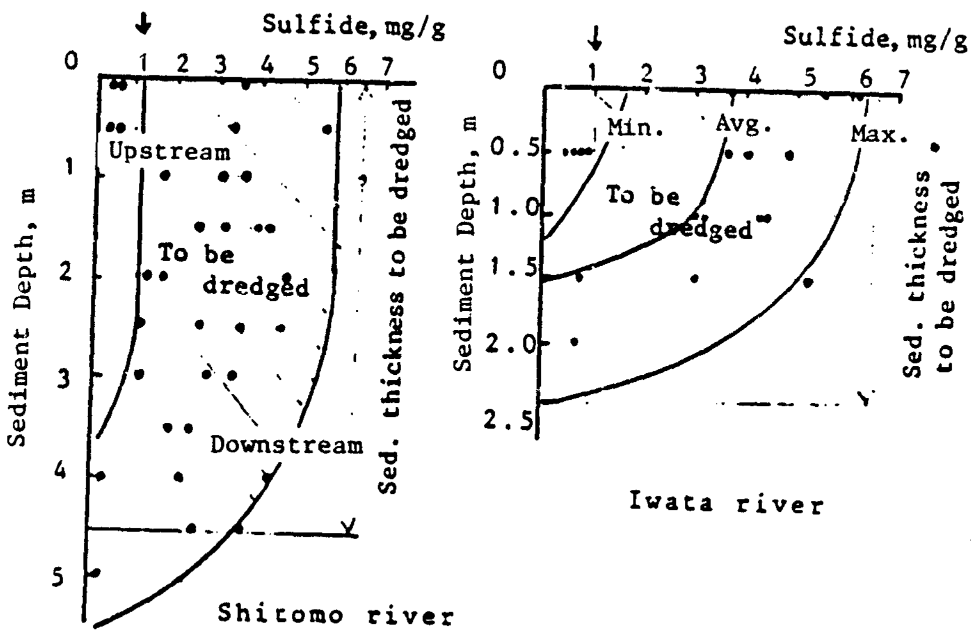


Figure 5. Vertical distribution of sulfide

From this, the following dredging depths were selected for the Shitomo River:

a. Downstream - 4.5 m

b. Middlestream - 3.5 m

c. Upstream - 2.5 m

For the Iwata River, the following depths were selected:

a. Outside harbor - 2.5 m

b. Inside harbor - 3.5 m

OUTLINE OF DREDGING WORK

Dredging

Figure 6 shows the dredged area in the Shitomo River and the disposal site located near the river entrance.

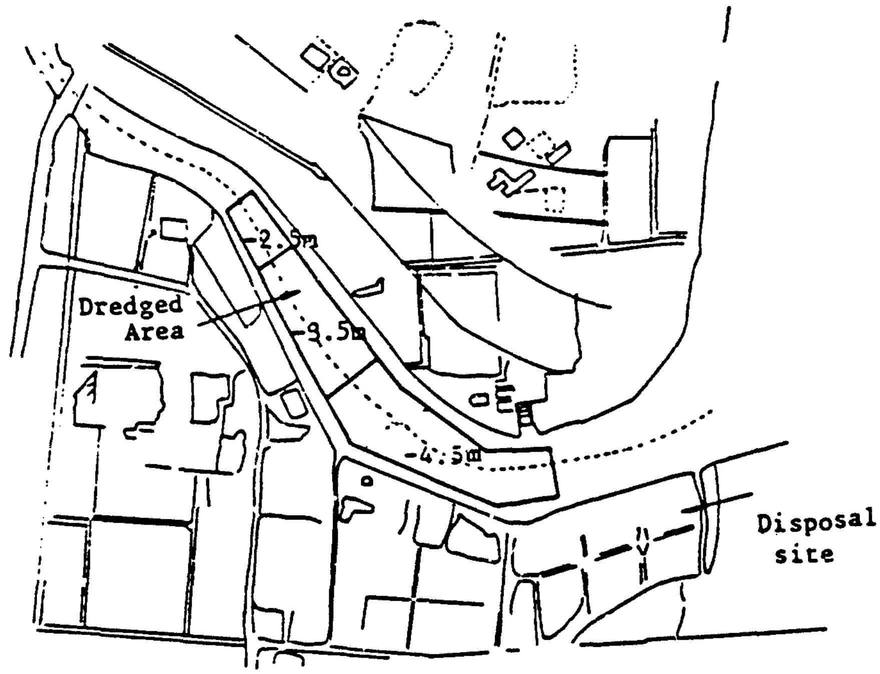


Figure 6. Dredged area in Shitomo River

The total amount of dredged material was 105,000 m^3 in 1980, 166,900 m^3 in 1981, and 50,300 m^3 in 1982--a total of 322,200 m^3.

Since the original dredge that operated at Shitomo River in 1980 had a diesel engine and was noisy, the nearby residents objected. Therefore, it was replaced by a dredge with an electric engine E-1000 PS in 1982.

Suction was used as a rigger cutter due to the hardness of the lower layers. Swing speed was 9 to 10 m/min; swing range was 45 to 50 m; and flow velocity of dredged material in the pipe was 4 to 5 m/sec. Downtime due to obstacles such as chips, wires, vinyl products, and screens was about 2 hr/day.

In order to lessen turbidity caused by dredging, especially in low tides, turbidity prevention sheets (called "silt protectors" in Japan and "silt curtains" in the United States) were placed above and below the dredged area.

The inspection points are shown in Figure 7. The inspection standards are shown in Table 1.

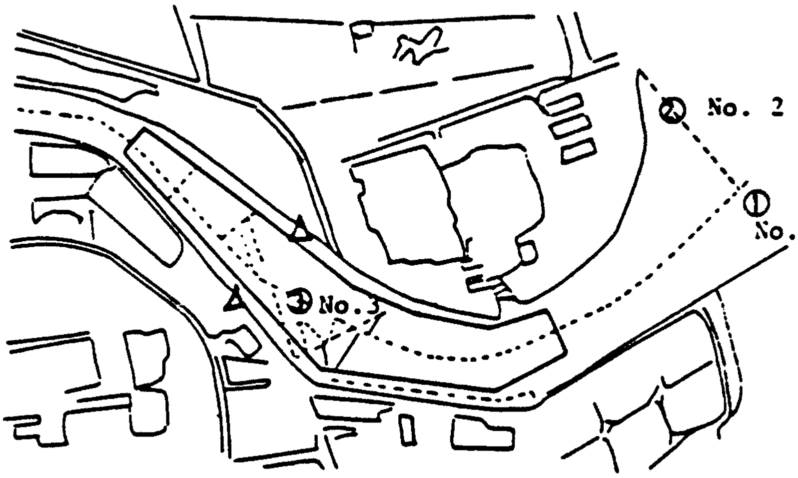


Figure 7. Inspection points (Nos. 1 and 2 are the basic inspection points. No. 3 is the auxiliary point.)

TABLE 1. INSPECTION STANDARDS

	Unit	Standard	Monitoring	Monitoring Point
ph		7.8 - 8.3	Two times/day	Basic two points
COD	ppm	Less than 5	Two times/day	Basic two points
DO	ppm	Less than 5	Two times/day	Basic two points
SS	ppm	Less than 50	One time/week	Basic two points
Turbidity	Degree*	Less than 50	Two times/day	Basic two points
Turbidity	Degree	Less than 50	Four times/day	Auxiliary one point

* One degree of turbidity indicates that there is 1 mg-kaoline in a liter of pure water (i.e., 1 degree = 1 ppm).

Compared to these standards, the operation results were as follows (Figure 8 shows the measured values of these indexes):

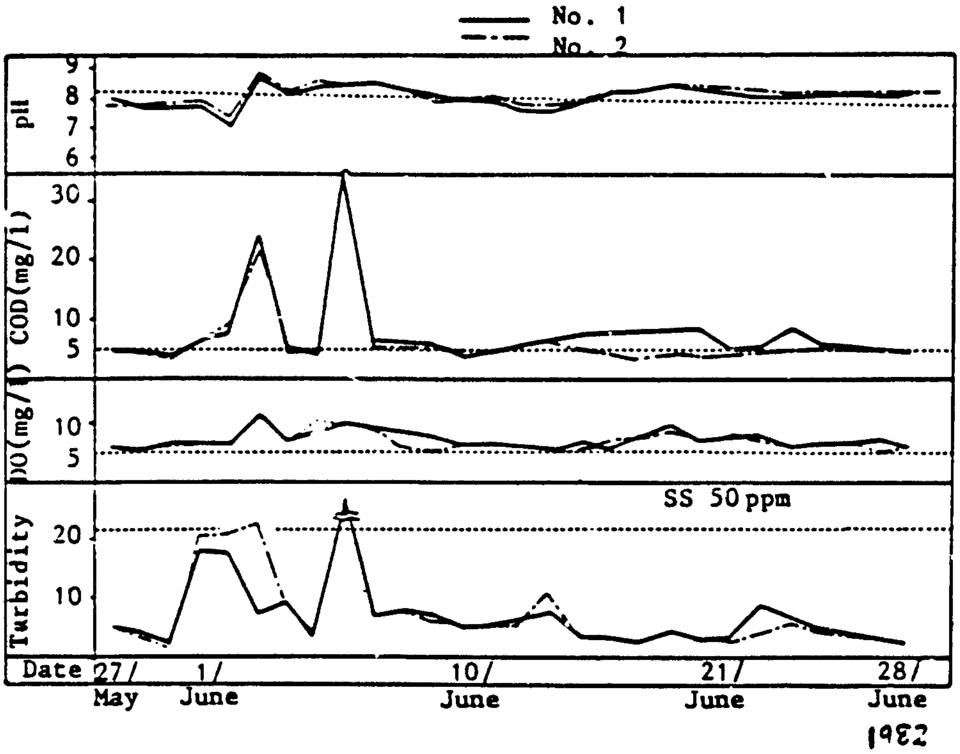


Figure 8. Measured values

a. pH. The measured values during the work were mostly 7 to 8 and therefore met the standard.

b. COD. The measured values of COD remained mostly within 5 to 10 ppm.

c. Suspended solids (SS). The concentrations of suspended solids were less than 50 ppm. Most concentrations were less than 20 ppm.

d. Turbidity. Turbidity did not create a problem. The measured values were less than 50 ppm (SS).

The dredging operation was judged acceptable since the inspected results met the standards in Table 1 except for COD, which remained mostly within 5 to 10 ppm.

Disposal

The dredged material was conveyed hydraulically to the disposal site near the river entrance (Figure 9). At the disposal site, deodorization and spill water treatment plants were constructed as mentioned in subsequent paragraphs. The conveying and disposing of dredged material went smoothly since the disposal site was located near the dredge.

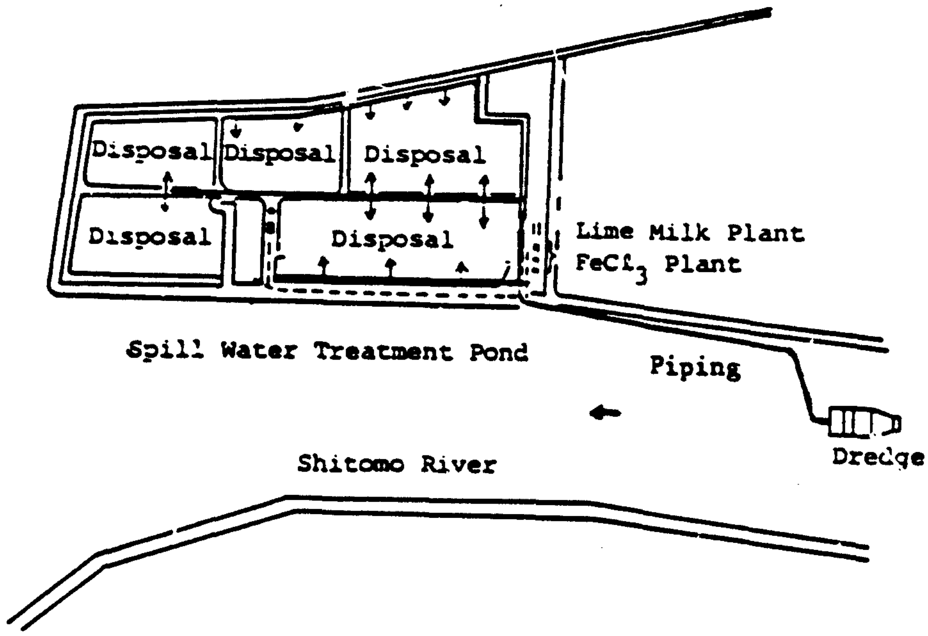


Figure 9. Disposal site

Deodorization and Spill Water Treatment

Deodorization Plant

The generation of odors from sediment is a phenomenon created when gases separate from the sediment via bacterial action such as sulphate-reducing bacteria in anoxic conditions.

Organic sulphur compounds are produced when the oxidation and reduction potential (ORP) of sediment is 0 to 200 mV. Therefore, to prevent odors, the absolute value of ORP must be lowered, i.e., decrease the anaerobic conditions. To do this, iron chloride was used because its effectiveness has been verified by laboratory tests. It is also known that the addition of slaked lime to iron chlorides makes the deodorizing action more effective since sulphur compounds react chemically with iron chloride and reduce free sulfide, the odor-causing substance.

Iron chloride (38 percent solution) was injected into the conveying pipe at the point of discharge and at a point 50 m from the discharge point. Slaked lime milk was added to neutralize the liquid containing iron chloride. Iron chloride and lime milk plants are shown in Figures 10 and 11.

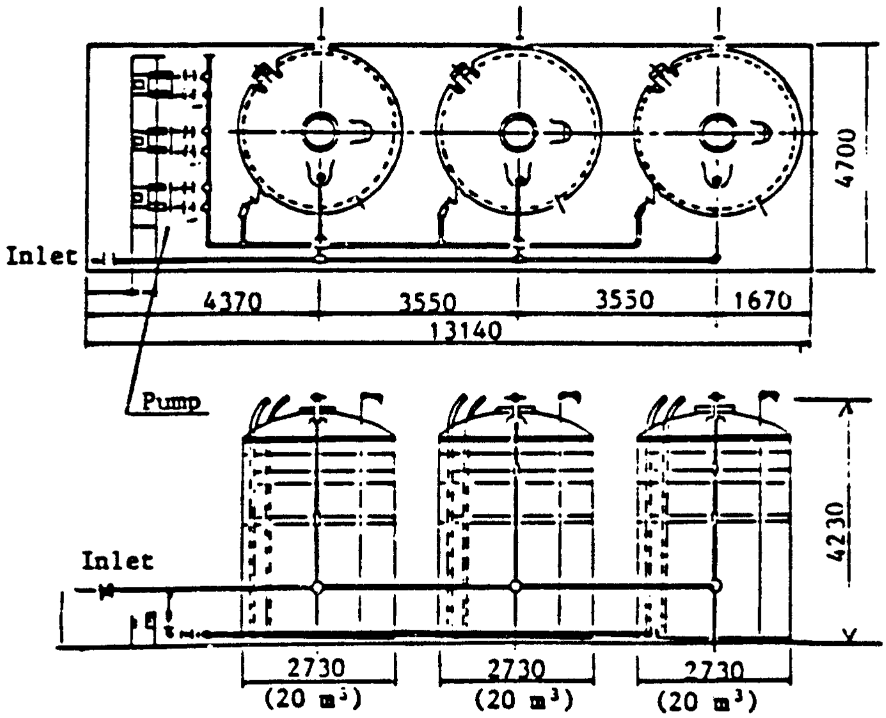


Figure 10. Iron chloride tanks (units in millimeters)

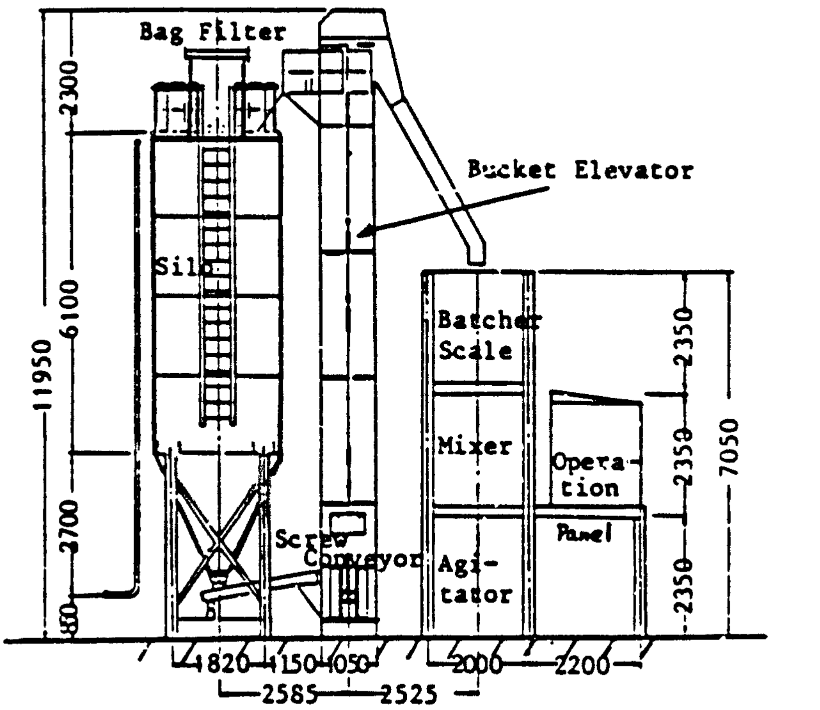


Figure 11. Lime milk mixing plant (units in millimeters)

The annexed quantities of deodorants were as follows:

a. Dredged material: 3,000 m^3/hr, average

b. Iron chloride: 1,000 ppm, average

c. Slaked lime: 250 ppm, average

The standards for odor inspection are shown below:

	Measure Pt.	Standard	Monitoring Times During Operation
H_2S	Leeward of outlet	0.02 ppm	10
Methylmelcaptan	Leeward of outlet	0.002 ppm	3

The measured values were all under the detection limit of 0.0005 volume per volume (v/v).

Spill Water Treatment

Since the hydraulically dredged material contains large quantities of water when it is disposed in ponds, spill water has to flow over into the sea. If the spill water is untreated, secondary pollution of adjacent seawater results. Therefore, it is necessary to treat spill water. In this case, treatment consisted of a sedimentation pond system with the coagulating agent PAC. A flowchart of the treatment system is shown in Figure 12.

Anionic flocculants were first injected into the slurry pipe before the inlet of the primary settling pond. To enhance secondary sedimentation of suspended solids, small quantities of flocculants were added a second time. Coagulant PAC was added at the inlet of the secondary pond to promote coagulation by polymerization.

The added quantities of coagulants were as follows:

a. Polymer, 5-10 ppm, primary

b. Polymer, 1-3 ppm, secondary

c. PAC, 50-100 ppm, secondary

Inspection of Water Quality

For the monitoring and inspection program, the predredging water quality was measured (Table 2).

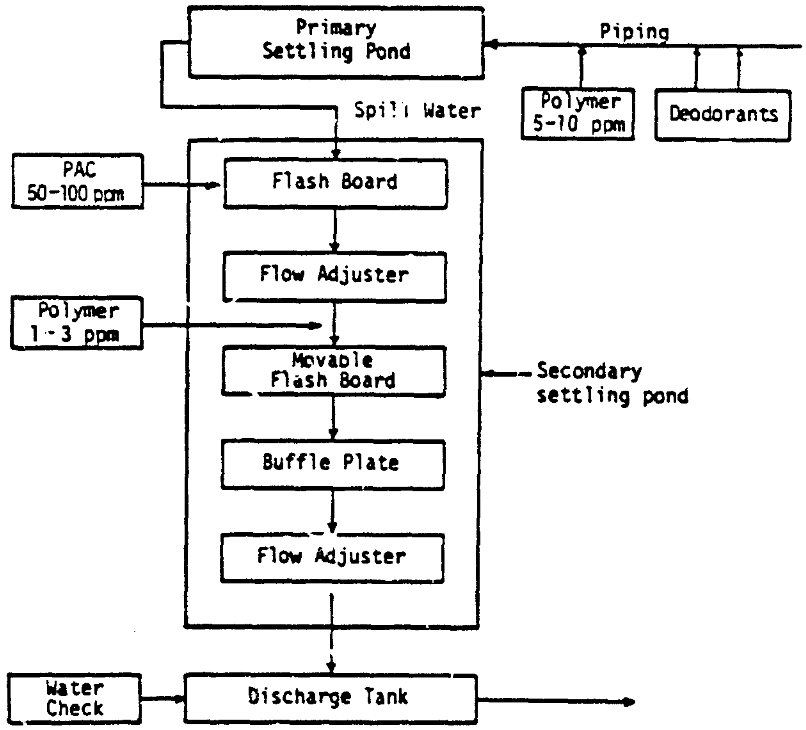


Figure 12. Flowchart of spill water treatment

TABLE 2. PREDREDGING WATER QUALITY

Parameter	Seawater Mean	Seawater Range	Riverwater (Shitomo) Mean	Riverwater (Shitomo) Range
pH	8.1	7.2 - 8.2	8.2	7.2 - 8.7
COD, mg/ℓ	4.7	2.9 - 7.1	5.2	3.3 - 10.0
SS, mg/ℓ	18.9	5.0 - 65.0	26.0	5.0 - 140
Turbidity, degr.	8.0	3.0 - 17.0	10.6	3.9 - 12.0
Hydrogen sulfide, v/v ppm	--	--	0.0022	ND - 0.025
Methylmelcaptan, v/v ppm	--	--	--	--

Considering these predredging data and general environmental standards, the inspection criteria selected are presented in Table 3:

TABLE 3. INSPECTION CRITERIA

pH	At discharge tank	5.8-8.6	Two times/day
COD	At discharge tank	Less than 25 ppm	Two times/day
SS	At discharge tank	Less than 50 ppm	Two times/day
Turbidity	At discharge tank	Less than 50 ppm (SS)	Two times/day

Compared to these criteria the operation results were as follows:

a. pH. The measured values during dredging were mostly 7 to 8 ppm and therefore passed the criteria.

b. COD. The measured values of COD during dredging remained within the criteria of less than 25 ppm.

c. SS. The concentrations of suspended solids were less than 50 ppm; most were less than 20 ppm.

d. Turbidity. There was also no problem with turbidity since the measured values were less than 50 ppm (SS).

CONCLUSIONS

After completion of the dredging work in Shitomo River, the foul odors disappeared completely. There were no more complaints concerning the odor from residents. It was also noted that water birds, fish, and shellfish increased. It appears there are benefits from dredging.

For any pollution control project it is most important to conduct the work safely and smoothly without complaints from local residents. From this point of view, our work achieved its goal. However, work still remains to determine to what degree the river estuaries of Tsu-Matsusaka Harbor have been rehabilitated.

SUBSURFACE INVESTIGATION FOR DREDGING PROJECTS

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ABSTRACT

Dredging and tunnel projects have achieved considerable notoriety within the geotechnical community. In reviewing the history of many of these projects, it becomes apparent that the reputation arises not from a failure to adopt so-called "state-of-the-art" technology, but rather a failure to organize investigations to address anticipated problems and to understand the significance of the data acquired. Even when these two elements are present, projects flounder when those charged with executing the work do not have a clear grasp of the engineering properties of the materials they are likely to encounter. As dredging techniques are more frequently being used to correct environmental problems, the techniques of investigation and data management will assume greater importance. The problems of establishing the types of data to be acquired, the extent of the data, and how it is to be used are still with us. Failure to address these problems rigorously results in excessive costs, unsatisfactory project results, and, in some cases, abandonment of projects altogether. This paper relies upon some old and simple concepts of experimental statistics to assist in quantifying the reliability of subsurface data. Only rarely is this technique used in practice and yet it is a powerful tool when it is combined with experience.

INTRODUCTION

Dredging projects are usually characterized by the need to move very large volumes, often over substantial distances. They include two particular characteristics that contain the seeds of financial loss. The movement of material is dependent upon the performance of a single machine and the entire operation is conducted at sea. These must be key points to an investigator. Changes in equipment, procedures, and schedules that can be reasonably accommodated on land are not so easily done at sea. For these reasons, the degree of accuracy required in subsurface investigation for dredging projects exceeds most land-based projects. Rarely in their careers will geotechnical engineers be asked to define subsurface conditions over such vast areas, in such detail,

and in such a hostile environment. The enterprise demands a sense of humility because small errors are multiplied by large volumes and large fixed costs.

It is likely that in the foreseeable future a substantial number of large dredging projects will be channel and harbor deepening projects to accommodate the ever increasing size of vessels. Some will be undertaken simply to remove polluted sediments that have accumulated over many years. In either case, the nature of the work will often require relatively shallow cuts over broad areas in existing facilities where environmental and social considerations immediately become important. Particular techniques that may have been acceptable 20 years ago are no longer acceptable. Investigations must be conducted with that understanding. The requirements of environmental permits alone put severe constraints on altering techniques once the work is under way, even when that is possible organizationally and mechanically. These matters must be understood if a coherent and useful investigation is to be made.

STEPS OF INVESTIGATION

The purpose of a subsurface investigation, in its broadest sense, is to define the nature of the materials likely to be encountered. The last part of that sentence has become a classic in contract law in the United States. It has been the basis for a great number of lawsuits, partly because we have failed to bring accuracy to our work. The purpose of a subsurface investigation is to adequately describe the nature, engineering properties, and variability of the materials likely to be encountered. While the issue of variability is generally recognized, it is usually addressed by incorporating disclaimers into the project documents. When geotechnical engineers disclaim responsibility for their work, that responsibility is thrust elsewhere. It is almost inevitable that the responsibility placed elsewhere is less easily met. These points are made because in most countries, in one form or another, the practitioner of geotechnical engineering conducts his technical business in a framework of economic and legal responsibilities.

Figure 1 has been prepared to outline the principal elements of a subsurface investigation. Figure 1 does not address projects that are designed principally as environmental efforts. That is a separate subject requiring its own format. However, developing the parameters will be similar. The steps are perhaps deceptively simple. However, when one or more of these steps is overlooked, there is invariably some missing piece of information that proves crucial to the project. It is useful to describe, at least briefly, the nature of these steps.

Literature Research

This must be the first step in the investigation. While the information tends to be global in nature, it will normally at least answer the question of whether the work is in rock or unconsolidated deposits. Most often it will provide considerable detail on local deposits and will certainly provide an early basis for planning the rest of the investigation. The geology of the area and of the site specifically will provide a knowledge of the geologic development of the area and hence, to some extent, the variability. As a practical matter, it will provide enough data so that preliminary studies of the layout, scheduling, and economics can begin. Most western countries

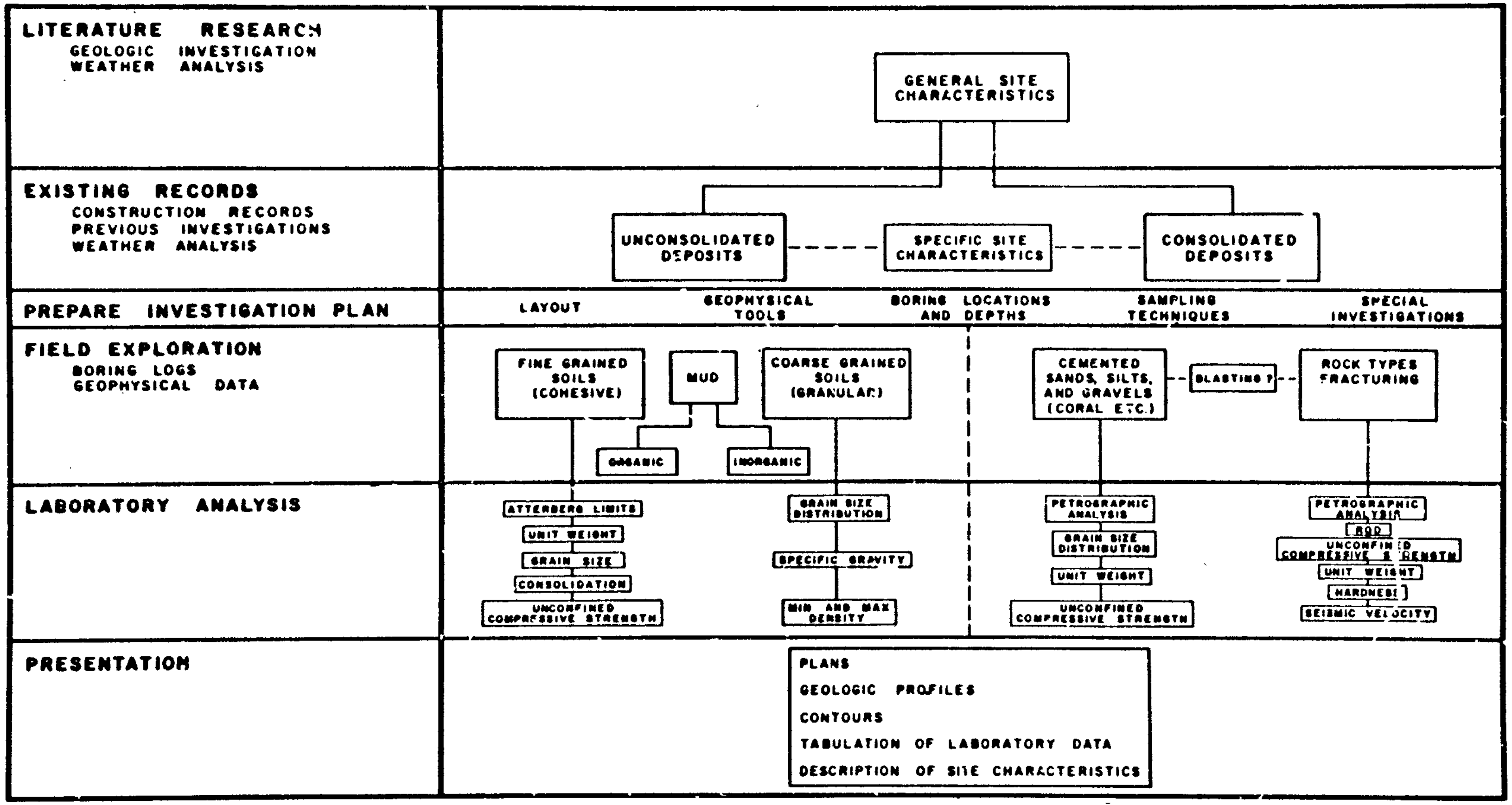

Figure 1. Development of subsurface investigation program

maintain excellent libraries of geological information that are available through universities and government agencies.

The cost of marine investigation is high relative to other types of projects. The high cost is influenced by the equipment that must be mobilized and the impact of weather. A thorough study of available weather data should be made so that correct equipment selections are made and the matter of scheduling can be addressed. That information is easily accessible but frequently overlooked in planning the field portion of the investigation. Information acquired through literature is the least expensive of the information that is required for the project.

Existing Records

The records of previous studies and construction are an essential source of information. Where they exist, they will narrow the types of materials likely to be found, isolate problems peculiar to the site, and help define the variability of materials. In unconsolidated deposits particularly, dredge production records can provide critical information on changes in subsurface conditions not otherwise apparent. It is often possible to establish the parameters that are likely to be most critical to progress by analyzing previous records. It is also in details of previous construction records that the broad limits of variability are likely to be established.

Investigation Plan

Figure 1 has been prepared to show the stages of investigation with particular emphasis on the parameters that must be established for various subsurface conditions. It is impractical and probably unnecessary to pursue each branch of the figure. The essential point is that each element in the figure must be examined and executed or deleted only on the basis of a rational analysis of the project requirements.

Let us assume that the literature research shows clearly that a hypothetical channel and harbor deepening project indicates that the excavation will be in rock with perhaps negligible overburden resulting from shoaling. The next phase of the investigation is to establish the locations of borings, their depth, and total number. As a part of this process, it is likely to be useful to conduct geophysical testing because it is impractical to attempt to describe the site with any degree of accuracy using soil borings alone. Channels are ordinarily measured in miles and harbors in millions of square yards. The task of defining the materials below the sea in these areas is formidable.

The principal tool today, and likely to remain so for some time, is the boring. This device gives us a physical sample from which we determine most of our parameters. From these borings, an experienced engineer can derive enormous insight into the character of the project by simply examining the material. For purposes of illustration, emphasis is placed on some rational method of selecting borings, but the process is equally important in selecting samples. It is at this stage of the project that sampling requirements must be defined with respect to the needs of the project.

In trying to establish a useful plan of borings, it is wise to divide the project into several elements. This can be done on a purely geometric basis or, preferably, where the data exist, into elements characterizing different known subsurface conditions or different physical properties of the project. Most of the data should have been gathered in the literature research and the review of previous construction records. Figure 2 illustrates this point.

In the example, there is a distinct channel project that crosses a physical boundary. Section 1 is excavation in materials that have not been previously dredged and so no physical data from previous construction are available--"new work" in the complete sense. It is the most seaward element and so the work is most influenced by sea conditions. It is likely to be the deepest work because in this zone vessels require not only the normal keel clearance acceptable in the harbor, but sufficient keel clearance to accommodate ocean swells. It is reasonable, therefore, to isolate this element because the investigation here is more critical to the orderly progress of the construction than it might be in the harbor where there is greater latitude to accommodate unanticipated conditions. This element is about 2500 ft long and 500 ft wide.

It has been shown (1) that a systematic sampling pattern is more efficient than a random scattering of samples. For this reason, if there is no reason to the contrary, a pattern of borings spaced along the toe of the cut at approximately 500-ft intervals is likely to produce a reliable sampling of the section. Obviously that is not a "rule" in any sense. It is a rational estimate of what is required if the data generated produce a coherent pattern. While we understand the desirability of knowing investigation costs before the project begins, that cannot be the overriding consideration if the total cost of the project is to be estimated with confidence.

The next point is embarrassing to make and it would not be made except that it has been violated so many times. When drilling rigs are mobilized for sea duty, they should be staffed and supported by the most experienced engineers. They must be capable of assimilating, reducing, and analyzing data as it is recovered. Perhaps more often than not, the initial boring plan will disclose differences that are unresolved with the existing data. Dredging projects extend over such large areas that it is likely some significant differences will appear. When that occurs, borings are drilled between those that show significant differences in subsurface conditions. That process is continued until the conditions revealed by intermediate borings are those anticipated from previous borings and samples. The technique requires fewer borings than one would be inclined to assume. The cost of that approach is correctly weighed against the risk of having one large, expensive machine encounter conditions for which it is not well suited. In dredging, the costs associated with mobilization alone are enormous and lost time is often counted in seasons, not days. So while we have not agreed precisely on the number of borings and their locations, we have agreed on how this matter will be determined.

The second problem is to define the depth of borings. Deepening a channel in rock (coral and cemented sands and gravels are included in this category) provides some interesting insights into an otherwise simple problem. Both hydraulic and mechanical dredges lose efficiency in shallow cuts. For

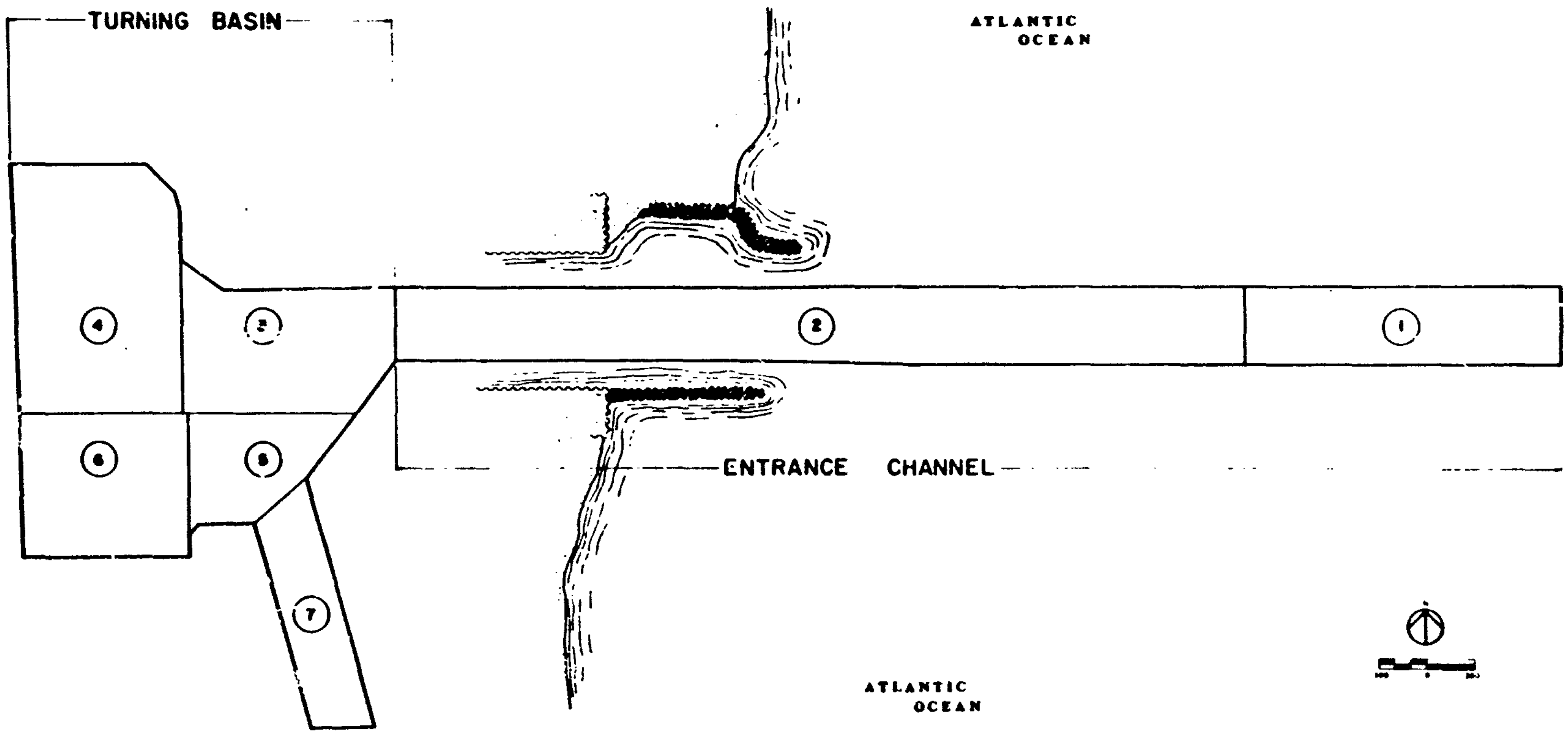

Figure 2. Example plan of borings by dividing project into several elements

this reason alone, one ought to be cautious in approaching a deepening project. Incredibly, subsurface investigations often reach just to grade or only slightly below. In the United States, the Corps of Engineers normally provides for some depth below required grade (called the overdepth) in which the contractor is payed for material removed although he is not required to remove it. That is a useful concession to reality because the heavy equipment in rolling seas cannot cut with the same precision as a scraper on land. So, to begin, the borings ought to extend at least to the overdepth. That, however, is still inadequate, particularly if a decision is to be made regarding blasting. If, for example, there is less than 2 ft to be removed to grade, the analysis of blasting requirements will depend upon a knowledge of the material for a depth of 5 to 10 ft below that depth.

Even where blasting is not an issue, some means must be found to remove the rock efficiently and rarely can that be determined only from the nature of the rock above grade. So, at least in the instance where rock or rocklike materials are encountered, the depth of the boring should be at least 5 to 10 ft below required grade.

There is a final comment that is appropriate to this issue. We are inclined to view the costs of borings in terms of cost/foot. That is sometimes misleading because at sea that cost is so heavily influenced by mobilization, moving between borings, and lost time due to weather conditions. Once a drill is positioned over a boring and drilling, the cost of deepening a hole by a foot or two, or increasing the number of samples, is relatively inexpensive. According, planning an investigation based on minimum lengths of borings does little to reduce costs yet incurs substantial risk.

Section 2 in Figure 2 is the portion of the entrance channel that has been dredged previously. There should be a wealth of knowledge preserved in various archives. A study of these records is essential in planning the investigation for this section. Rather than basing the number and locations of borings on a fixed grid system, it should be possible to select locations based on some degree of variability that is already known. That condition should be accounted for in the beginning. Once those borings have been located, the remaining borings are located on the basis of completing subsurface profiles. That is, additional borings are then located so completed profiles can be constructed by exploring conditions in specific areas of interest.

The interior harbor (turning basin and berths, Sections 3-7) will demand the same process of investigative planning as described above, but with additional considerations. Now some consideration must be given to existing facilities. Existing buildings, sheet pile walls, unloading structures, and similar construction already in place require particular attention. The mere presence of existing facilities implies that previous investigations have been made and will be useful. The investigation should address two principal issues. The first is that of stability of structures following the planned improvements. At the very least, it is likely that a deepening project will reduce support for some structures. The investigation must provide the geotechnical parameters that will allow an analysis of stability of structures following completion of the project. This should include sufficient data so that recommendations for corrections to existing structures can be made if

that is indicated. The type of structure and potential difficulty will dictate the number of locations of the borings, their depths, and the type of samples required.

The second principal issue concerns the effects on harbor facilities during construction. Vibrations, noise, and other environmental considerations are essential. Blasting, for example, while practical in many cases, may not be permissible in some areas whereas there is no problem with the method in other areas. Where the work requires dredging near residential areas it is important to have a clear understanding of the types of materials to be dredged and formulate plans for excavating these areas. What kind of excavation is suitable? What are the noise and vibration characteristics? Should there be limitations on the length of the working day? These are all questions that are, at least in part, related to the nature of the materials being dredged. In these areas, the investigation can be useful in providing data from which estimates of turbidity can be made.

There is no simple rule to offer as a guide for determining the details of the physical investigation within the harbor, or, for that matter, any portion of a large dredging project. That is not to say, however, that the investigation must be planned in a vacuum. Outlined above and in Figure 1 are the steps of the investigation and the matters that must be addressed by the investigation. The layout and depth of borings have been discussed briefly only to illustrate a process.

It is in these stages of the investigation that the number and types of samples must be determined, at least approximately. That is an important task and one that should be pursued on a rational basis. Statistical concepts that are useful in establishing a basis for selecting sample numbers are discussed in a subsequent section.

There is a natural division between the Investigation Plan and the subsequent elements in Figure 1. The previous elements, while requiring technical expertise and experience, are principally organizational and administrative tasks. Those that follow are matters of execution and analysis. These are presented not so much for the purpose of discussion, but to complete Figure 1 and to illustrate the usefulness of defining the problem clearly. Having established a framework for investigation, it is appropriate to abandon the general discussion and concentrate on the treatment of data acquired in the next two phases, Field Exploration and Laboratory Analysis.

Geotechnical engineers in particular, and engineers in general, tend to excuse a lack of reliable subsurface information as resulting from two characteristics they allege are beyond their control:

a. Lack of sufficient funds.

b. The inherent variability of subsurface conditions.

The first lament is a universal one. There are never sufficient funds to accomplish all the goals. Its solution lies in the matter of establishing priorities, understanding clearly what is needed, and then making persuasive argument.

The second lament is a bit more subtle. Perhaps a good analogy to examine is that of the ordinary picture puzzle. The manufacturer will advertise a 5000-piece puzzle with no two pieces alike. But the pieces form a single picture. As in the case of most analogies, that is too simple but it gives perspective to the problem. In this instance, the pieces must be located and, more importantly, it must be decided when enough pieces have been gathered to construct a correct picture. The problem is to quantify the variability and reach a satisfactory "confidence level" that provides assurance that the correct picture has been assembled. In that regard, a statistical analysis is useful, but it is one that is rarely used. This technique is particularly valuable in its application to dredging projects because such large areas are being defined under such difficult conditions. It is important to know when adequate data have been gathered to properly define a site to avoid squandering budgets on repetitive but unnecessary data. Returning to the example that the project requires dredging in rock, for the purpose of illustration, the unconfined compressive strength of the rock has been selected as a key parameter that must be defined with some reliability. The exercise, however, is applicable to any of several characteristics, among them the Rock Quality Designation, another property of rock that is essential to estimate excavation characteristics. The technique can be applied to any randomly measured characteristic.

A relatively simple probabilistic evaluation, this parameter can be used to estimate the maximum standard deviation of the population at various confidence levels. That is a method of quantifying the risk that material may be outside the limits of the equipment. It is also possible to estimate the percentage of the population that will lie within certain minimum and maximum values, a process that is useful in making equipment selection.

Laboratory Analysis

Acquiring rock cores at sea is difficult and costly. Nevertheless, the Rock Quality Designation, Seismic Velocity, and Unconfined Compressive Strength are the essential parameters needed to plan the project. The Unconfined Compressive Strength Q_u is used as an example in analyzing data because it represents the data acquired from an actual dredging project.

In this case, the subsurface investigation included the results of two unconfined compressive tests of the rock to be dredged. The significance of those tests will be examined later. What is important is that the project encountered extreme difficulty encountering rock that could not be dredged by the equipment as it was mobilized. As a result, an extensive testing program was undertaken that produced a total of 99 tests.

Since the data exist, by generating random numbers from 1 through 99 to represent each test, it is possible to study the data and quantify the results as they might have been generated in the course of the investigation. The tests represented values of Q_u from 360 psi to 12,000 psi, a formidable range. For purposes of illustration, only a portion of the total number of tests is necessary. Table 1 represents the results of tests represented by the first 12 random numbers.

TABLE 1. RANDOM NUMBER TESTS

Random Number	Corresponding Unconfined Compressive Strength psi
54	4894
69	1886
79	1521
37	3587
85	4074
75	2761
35	5778
49	6313
76	1414
46	5854
40	3199
22	1789

When it is intended to measure some characteristic (such as the unconfined compressive strength) of a large population (the rock deposit to be dredged), it is neither practical nor necessary to test the entire population. Instead, some portion of the total population can be sampled in a random manner and inferences can be drawn about the population based on the results of the limited sample. This approach has been found to be very effective in predicting the characteristics and behavior of materials in geotechnical applications. The number of samples tested establishes the confidence levels (probability) of inferences made about the population. The goal of probabilistic evaluation in the context of this discussion is to quantify the confidence levels that the mean and standard deviation of the population characteristics being measured will fall within. It can also be used to establish the confidence levels for certain critical values. Stated in a simpler way, the mean and variability of a sample are used to predict the mean and variability of the population. It is important to remember that a sample in this discussion refers to a group of tests. A group of tests is a sample of the population.

There is substantial evidence that many soil and rock characteristics conform to a standard-normal distribution. The normality of such geotechnical distributions can generally be anticipated by the Central Limit Theorem and the fact that these characteristics develop in the population as the result of many random and unrelated influences. Some degree of skewness should be anticipated in the distribution of unconfined compression strength since this characteristic is censored at a strength of zero, as are many characteristics of interest to geotechnical engineers. That is, while no data can be plotted below zero, there is theoretically no limit to values greater than zero. Accordingly, the population is said to be censored, capable of producing a right tail but not a left. It is, however, reasonable to assume a normal distribution for the unconfined strength of the population. Figure 3 is a histogram of all values of Q_u ($N = 99$). An analysis of the 99 tests does in

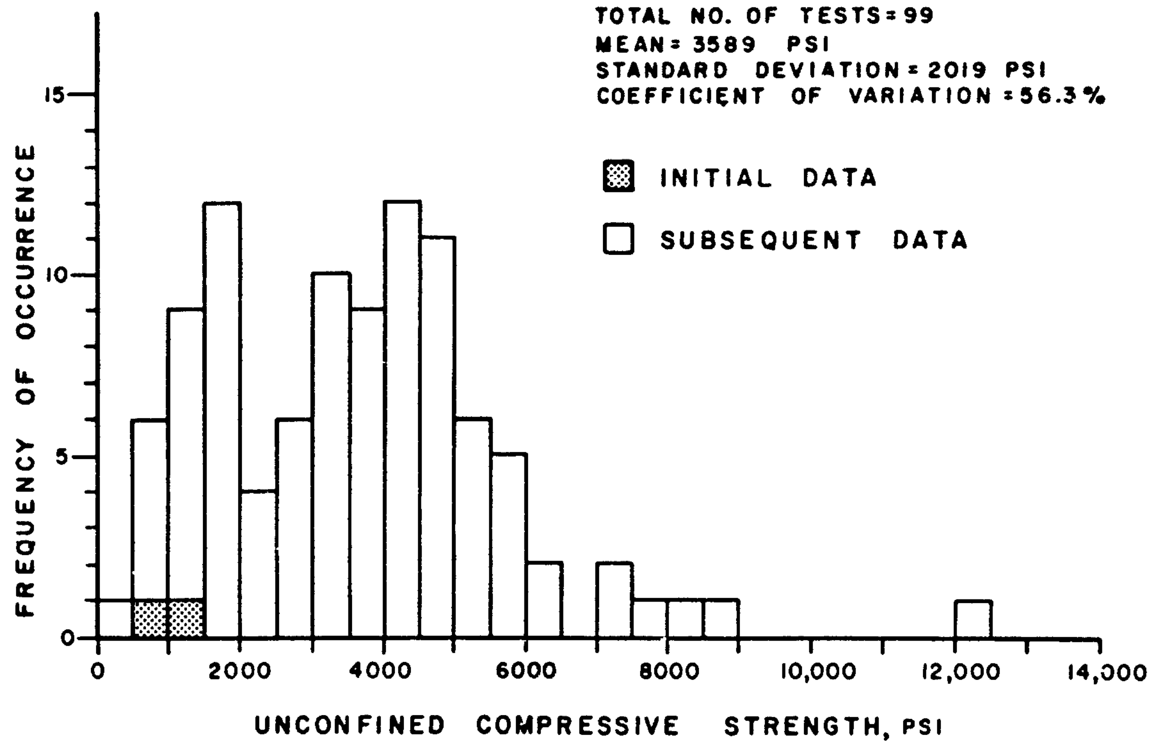

Figure 3. Histogram of all values of Q_u

fact produce values of skewness and kurtosis that compare favorably with the theoretical values of 0.0 and 3.0, respectively. Accordingly, it can be analyzed using the technique described below.

Based on standard statistical techniques for small samples, it is possible to determine the probabilities that the mean strength of the population will not exceed certain values critical in determining equipment requirements and production rates. While it is possible to calculate the probabilities of the mean strength falling below a specific value, in this instance we are interested in determining what the maximum average strength might be and how sure are we of that result.

The upper limits of the mean strength of all the rock (the population) can be estimated for various probabilities using the single-sided Student's t Statistic for small sample evaluation. This has the form:

$$Q_u(P) \leq \bar{x} + t_{(p,v)} \frac{s}{\sqrt{n}}$$

where

$\bar{x}$ = sample mean

$t_{(p,v)}$ = Student's t distribution for a probability of P

v = degree of freedom (n-1)

s = standard deviation of the sample

n = number of tests

The equation is read as:

There is a probability of P that the mean strength of the population will be equal to or less than the sample mean plus the standard deviation of the sample mean times the Student's t distribution for that probability.

While that description of the equation is correct, it is not illuminating to the practicing engineer. The relationship can be phrased in a more useful way.

The probability is P that the mean strength of all the rock will not exceed a specific value of Q_u .

Because of the cost associated with acquiring and testing rock samples, it is important to know how many tests are required to produce a useful result. The result must be useful in that it must clearly convey the range of values within which the rock strength will occur. That point is clearly illustrated by examining the data set in Table 1.

If it is assumed that the investigation was limited to only two tests, the maximum value of the anticipated population mean for a 95 percent confidence level can be calculated from the following expression:

For test numbers 54 and 69

$$\bar{x} = 3390 \text{ psi and } s = 2127 \text{ psi}$$

$$Q_u(P = 0.95) \leq 3390 + \frac{tp(2127)}{\sqrt{n}}$$

where

n = total number of tests in the sample

tp = Student's t Statistic selected for a probability of 0.95 and the degree of freedom, n-1; tp = 6.31375

$$Q_u = 3390 + \frac{(6.32375 \times 2127)}{\sqrt{2}}$$

$$Q_u = 12,886$$

The result can be stated as follows:

There is a 95 percent probability that the mean strength of the population will not exceed 12,886 psi.

This estimate is based on only two samples and intuitively one is reluctant to draw too many conclusions from the result. That is, however, an overly pessimistic view. The process includes the variability or "chance"

that is inherent in using only two samples. That is precisely the value of the Student's t Statistic. That calculation can be repeated for various probabilities and various sample sizes. These curves are developed in Figure 4.

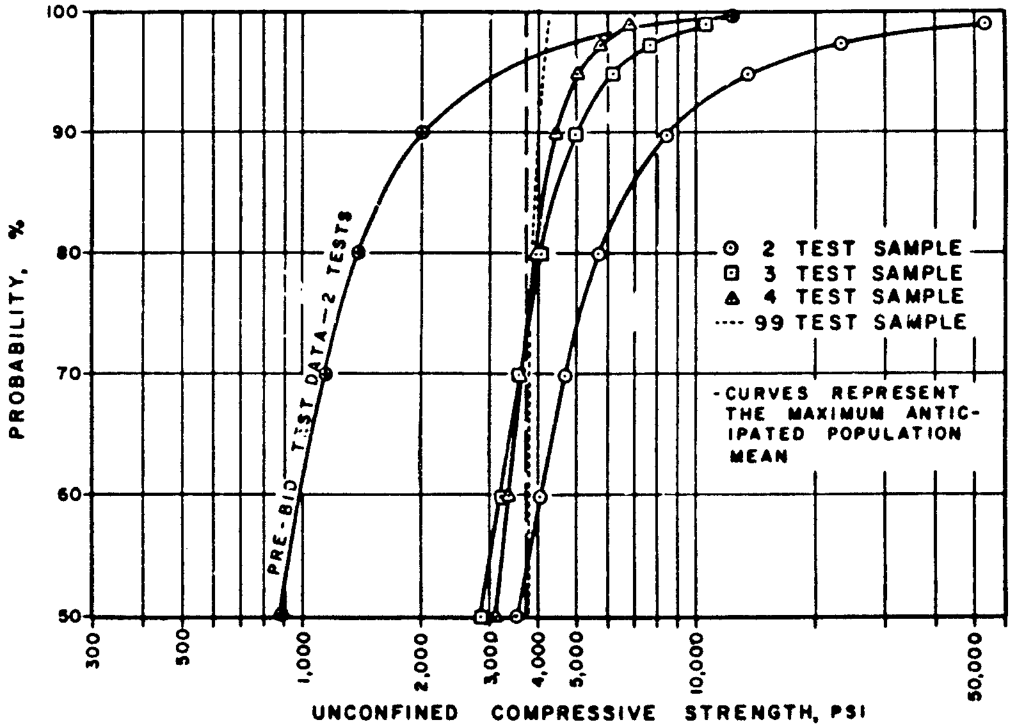

Figure 4. Influence of sample size on confidence level

Figure 4 illustrates several important points that should be explored. The mean strength does not vary significantly with the number of tests. At first glance that suggests a certain reliability to the data. However, a comparison of the curves for 2, 3, and 4 tests indicates that the probability that the maximum population mean will not exceed certain values is very sensitive to the number of tests for small numbers of tests. As a corollary to that, it may be said that the probability is relatively insensitive to the number of tests when the number of tests is large. That is the characteristic of the Student's t distribution. The point is clearly made below (2):

n	n-1	t(p = 0.90)	
2	1	3.07768	
3	2	1.88562	
4	3	1.63775	
10	9	1.38303	
99	98	1.29104	(Interpolated)

In the ordinary course of geotechnical practice, where the sampling is random and tests are conducted with precision, 10 to 12 tests will usually provide adequate confidence levels.

Figure 4 is a method of quantifying the variability of the parameter being studied. With this kind of analysis, an investigator has a rational basis for deciding when sampling and results of tests are adequate for the intended purpose.

The example used represents data acquired from a real project investigation and it is useful to assess the quality of the data that was actually used to estimate project requirements.

Figure 3 contains a shaded area that represents the data on which cost estimates were based. The shaded area represents two tests and it is obvious that they lie at the extreme low end of the distribution curve and hence do not reflect the characteristics of the population as they were ultimately defined. The anticipated maximum population mean determined from these two tests appears on the left of Figure 4. Maximum anticipated strength values based on only these two tests are significantly different from what would have been indicated if only four to six more random samples had been collected.

Together these curves show that it is essential to acquire a sample that is adequate to limit excessive deviations at relatively low probabilities. An adequate sample can be achieved by relatively few rock cores randomly selected and tested with precision.

Figure 5 is the same use of the Student's t distribution to depict a spectrum of the data. This has been constructed on the basis of the entire

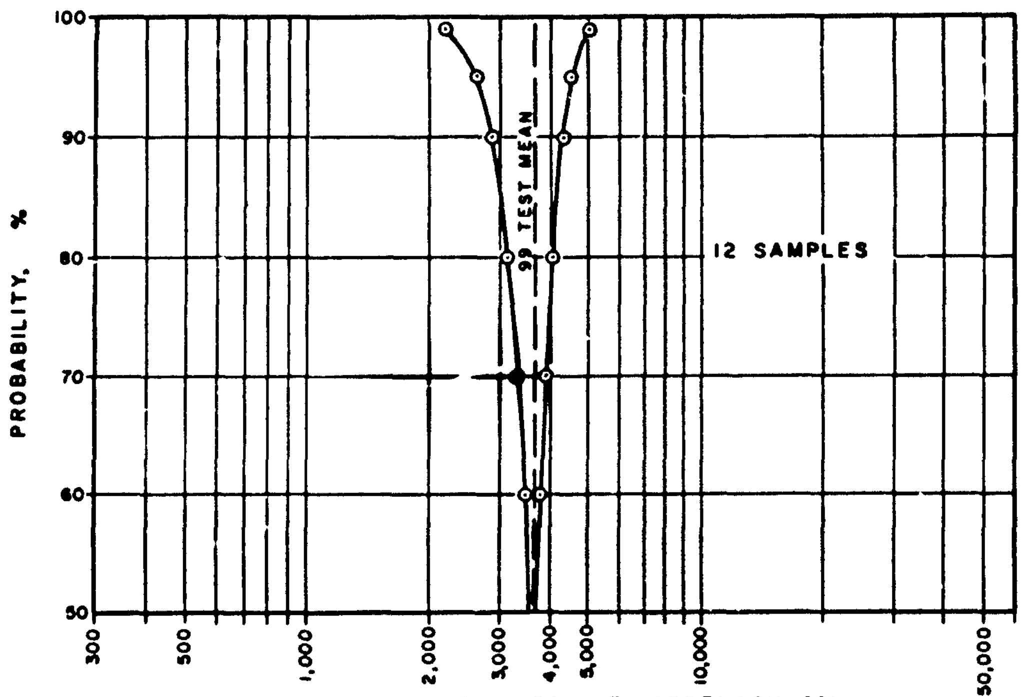

Figure 5. Limits of population mean as a function of probability

data set in Table 1 (12 samples). Figure 5 is a useful and reliable presentation of the data and one that clearly quantifies the variability of the parameter being measured in a way that is meaningful to those requiring the data. The essential point of Figure 5 is that it takes relatively few tests to provide a reliable definition of the range of an important characteristic.

Presentation

Geotechnical investigations are conducted by geotechnical engineers for the use of others. In that respect, they must be comprehensible to other than geotechnical engineers. In the field of dredging, geotechnical data is perhaps the key element entering into the estimate of project costs, which is of universal interest. It is exceedingly rare that a geotechnical engineer will find himself preparing cost estimates for a dredging project, although he may be consulted with respect to certain aspects of that data.

The last element of Figure 1 contains the normal mechanisms for transferring data from the investigator to the user and requires a brief comment.

The U. S. Army Corps of Engineers has authored many publications intended to provide guidance in the acquisition and dissemination of geotechnical data. They are excellent guides to investigation and presentation of data and they should be familiar to any geotechnical engineer who accepts the responsibility of a dredging project. One statement merits a direct quote.

> Particular attention will be given in clearly presenting those characteristics of rock that will convey to the contractor accurate information on excavation problems whereby he can determine what excavation methods and procedures will be involved. Complicated descriptions of scientific interest, but not pertinent to the excavation problem, will be eliminated (3).

If the term "materials" is substituted for "rock," the paragraph is sage advice of universal application in dredging.

The task of the geotechnical engineer remains that of describing the engineering properties and variability of the materials likely to be encountered. The techniques are well known. It remains only to make certain that these techniques are used and that the results are presented in a manner that is informative to those charged with execution of the project.

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BENEFICIAL USES OF DREDGED MATERIAL: AQUACULTURE IN DREDGED MATERIAL CONTAINMENT AREAS

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ABSTRACT

Aquaculture can be a profitable and biologically beneficial use of containment area real estate. Aquaculture in a dredged material containment area was first demonstrated by the Corps of Engineers (CE) with limited success in Texas in 1976. The Texas project documented that white shrimp could be grown to a marketable size and quality in an environment designed for and modified by dredged material disposal. Project economics at that time did not support the practical application of the concept. Currently, successful American aquaculture industries for oysters, clams, crayfish, catfish, trout, and other species, and developing industries for marine and freshwater shrimp, mussels, and other species indicate continually improving economic conditions and incentives for expanded aquaculture incentives. Progressive growth of American aquaculture is a result of advancements in culture and product processing technologies, more effective marketing strategies, and an increasing demand for fishery products by domestic and foreign consumers.

Containment area aquaculture offers several inherent economically attractive features. Dredged material containment areas are commonly diked and employ water level control devices. In some instances costs associated with land acquisition and dike and water level control device construction are absorbed wholly or in part by the Federal government or the local cooperator on the dredging project such as a city government or port authority. Freshwater and coastal containment areas are often located near favorable water sources, on water front property that might otherwise not be available to the aquaculturist, and/or near large market areas with established transportation routes.

At a time when commercial aquaculturists are saying that the lack of available coastal sites has been the principal restraint on the application of

commercially practical culture technologies, coastal lowland availability could be increased for culturists willing to operate in a containment area.

A CE-sponsored 2-day workshop on aquaculture in dredged material containment areas was conducted in 1982. The proceedings of the workshop are briefly summarized and include discussions about: site characteristics; site acquisition and permitting; contaminated dredged material; economics; pond design and construction; pond operation and management considering water quality, production, and disease control techniques; operational compatibility between dredged material disposal and aquaculture; and prospects for success.

The necessary, preliminary desk-top analyses have taken the idea as far as possible. Before the concept is likely to be tried by an American aquaculturist working together with coordinated CE dredged material containment operations, a successful, full-scale field demonstration will need to be conducted. Such a demonstration will probably require Federal subsidy.

BENEFICIAL USE OF DREDGED MATERIAL

The term "beneficial use of dredged material" describes the viewpoint that dredged material and dredged material containment areas (DMCA) are very often manageable resources. This positive viewpoint is being cultivated intentionally within the Corps of Engineers to assist the ever-challenging programs of dredged material management being conducted by Corps Districts. The preference for a positive rather than negative viewpoint of dredged material is the reason why some in the Corps discourage the use of the term "dredge spoil."

There are numerous examples of beneficial uses of dredged material and dredged material containment areas (1),(2). This paper will discuss aquaculture as one of the beneficial multiple uses of containment areas.

CORPS OF ENGINEERS INTEREST IN CONTAINMENT AREA AQUACULTURE

The point of view that active dredged material containment areas are unproductive, commercially unusable, and incompatible with local needs can be dispelled by demonstrating that there are situations where aquaculture can be a profitable and biologically productive use of containment area real estate.

The use of dredged material containment areas for aquaculture would directly benefit the Corps in several ways. It would improve future site availability by increasing the value of acreage leased to dredging project sponsors because landowners could enter separate and profitable lease agreements with aquaculturists. Aquaculture activities would also dispel the negative image of containment areas in the public eye, and generate a positive public image of the Corps and its activities.

AN EARLY FIELD DEMONSTRATION

Aquaculture in a dredged material containment area was first explored by the Corps during the Dredged Material Research Program. In 1976, Dow Chemical Company, under contract to the Corps, successfully cultured a crop of white shrimp (*Penaeus setiferus*) in an active containment area near Freeport, Texas (3). The location was a 158-acre containment area adjacent to the Gulf of Mexico along the Gulf Intracoastal Waterway (GIWW) (Figure 1).

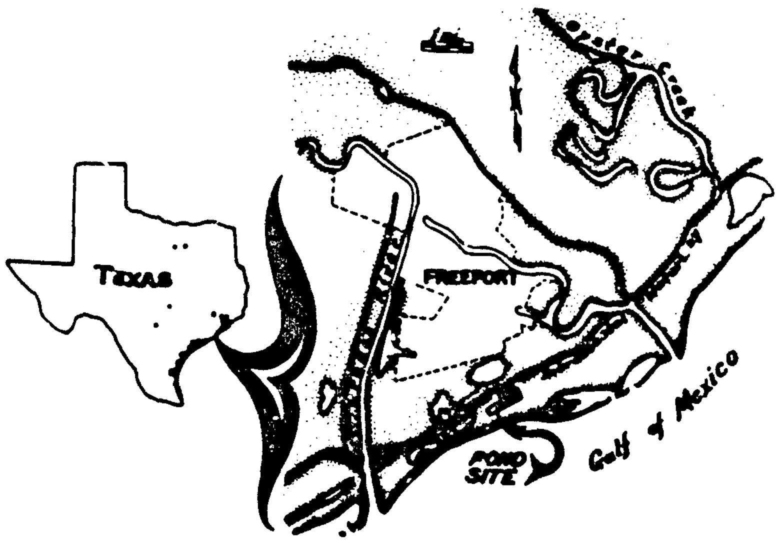


Figure 1. Shrimp culture pond site. Location of the shrimp pond site in dredged material containment area No. 85 near Freeport, Texas (3)

Approximately 3 months before Dow Chemical began its operations, nearly 1 million cubic yards of fine-textured dredged material was placed into the area. Because an area of 158 acres was too large to manage easily, it was partitioned by a 1000-ft-long internal levee to create a smaller 20-acre pond (Figure 2). The pond was filled with water from the GIWW and the water was poisoned with rotenone to destroy the predators and competitors that would tend to reduce the survival of the animals to be cultivated. Fertilizer was then added to encourage the growth of planktonic algal food for the juvenile white shrimp that were to be released into the pond. After stocking, shrimp were retained in the pond for 3 months without supplemental feeding. At the end of the 3-month period, shrimp were harvested, analyzed, and determined to be wholesome for human consumption.

This demonstration project permitted the conclusion that dredged material containment area environments are compatible with aquaculture in the sense that animals will grow, survive, reach marketable size, and be of marketable quality. No attempt was made to justify the project's production economics and it is certain that an economic analysis would not have been encouraging. The cost of postlarval white shrimp stock, limited acreage, and small size of the unfed white shrimp at the time they were harvested all contributed to extraordinarily high production costs.

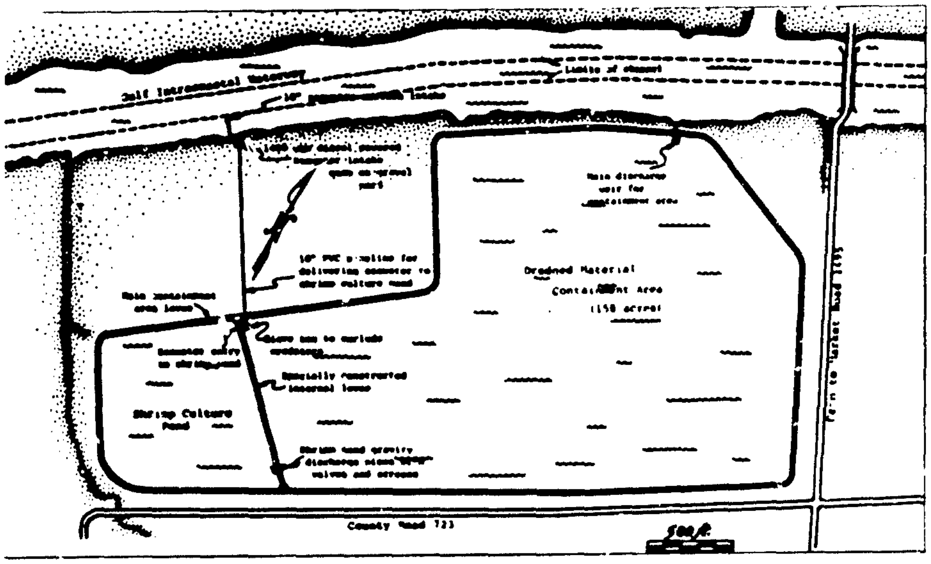


Figure 2. Galveston District dredged material containment area No. 85, showing shrimp pond, internal levee, and associated structures (3)

REVISITING THE CONCEPT IN LIGHT OF NEW TECHNOLOGY AND OTHER FACTORS

Advances in Aquaculture Technology

Many of the technology problems encountered which affected production economics during the early demonstration at Freeport have been reduced through continuing research on the biology and culture requirements of desirable plant and animal species. It is now possible, for example, under laboratory conditions to complete the life cycle of the white shrimp species used in Freeport. By manipulating the female shrimp's environmental conditions and hormone levels, it's possible to control the entire maturation process in the laboratory. Females can then be artificially inseminated. One advantage of this technology is a much reduced cost of obtaining juvenile shrimp compared with the cost of field excursions for capturing egg-carrying and recently mated female shrimp in the wild, and returning them to a laboratory for spawning. Another very significant advantage is that artificial control over the natural reproductive cycle permits production of juvenile shrimp whenever they are needed and allows production of multiple crops in a single growing season. The result is more efficient use of the cultivation area, higher annual production, and lower net production costs.

In the United States at the present time, important aquaculture industries exist for oysters, clams, crayfish, catfish, trout, and other species. New industries are developing for culture of shrimp, prawns, mussels, and others. These industries, and aquaculture-based fisheries, contribute hundreds of millions of dollars annually to the American economy and help reduce a major trade deficit (4).

Increasing Demand for Fishery Products and the Contribution of Imported Fishery Products to the National Trade Deficit

According to Lawrence, Chamberlain, and Hutchins (5), the dockside value of all U. S. fisheries is consistently more than $2 billion a year. In 1980, it was $2,237,202,000. In that same year, the United States imported fishery products valued at $3,648,082,000. These authors stated that the importation of foreign fishery products accounted for 10 percent of the national trade deficit in 1979. Using the shrimp fishery as an example, the value of the U. S. catch decreased from $471,573,000 to $402,697,000 between 1979 and 1980, whereas the value of shrimp imports for human consumption increased from $713,238,000 to $719,263,000 during the same period. They further predicted that the imbalance will increase because the U. S. demand for fishery products is constantly increasing at a time when fishery harvests are at or near maximum sustainable yields.

Apparently Favorable Economics of Containment Area Aquaculture

Dredged material containment areas commonly possess structural features such as dikes and water control devices that may enhance their suitability as multiple-use areas with aquaculture. In some instances, land acquisition costs (purchase or lease) and dike and water control structure costs are absorbed wholly or in part by the Federal Government or a local cooperator on the dredging project such as the city government or port authority. In cases where a Federal or local subsidy exists, the aquaculturist could be the beneficiary. Dugger (6) stated that the lack of available coastal sites has been the principal restraint on the application of commercially practical culture technologies. He used the term "availability" with reference to both the real estate cost and to the government's regulatory permitting process which affects consideration of aquaculture in coastal lowlands, particularly wetland habitats of the United States. Lunz and Homziak (7) stated that freshwater and coastal dredged material containment areas have several benefits related to desirable location: proximity to favorable water sources, on waterfront property that may otherwise be unavailable to the aquaculturist, and often near large market areas and established transportation routes.

Proposals to use coastal lowlands or wetlands for dredged material containment are subject to Federal and/or state wetland protection regulations. At least two different scenarios are apparent that would improve coastal lowland availability to aquaculturists willing to operate in a containment area. In the first scenario, obtaining permission to use an existing disposal area for aquaculture was precedented and seemed to be a relatively simple procedure. Unfortunately, the area for which permission was obtained was never used because of a shortage of capital. In the second scenario, the local, regional, and economic benefits described in a permit application that included both dredging-related and aquaculture-related incentives would be greater than the benefits described for a single-use project. The probability of a successful permit action is thereby improved.

Dikes that would serve to contain the dredged material would also serve to impound the water necessary for aquaculture. But the quality of dikes

constructed in different areas for the sole purpose of dredged material containment is highly variable as illustrated by Figures 3 and 4. The dikes

Figure 3. Double bayou containment area dike in Texas (photos in this paper were provided by Mr. Rick Medina, U. S. Army Engineer District, Galveston)

of an existing containment area that is under consideration for aquaculture may have to be modified to increase their height, adjust their slopes, or improve their water-retaining capabilities. However, at a new containment area that has been identified for multiple use, the dikes could be designed to permit both the containment of dredged material and the retention of water for the aquaculture operation.

Water control structures that are used to regulate water quality at containment areas could also serve to regulate water exchange rates and levels in an aquaculture pond, and could be used to drain the pond or concentrate the crop for harvesting. A weir-type structure (Figure 5) located within the dike perimeter system itself and the drop-inlet-type structure (Figure 6) located inside the dike perimeter are two designs commonly used in containment areas.

Compatibility Between Aquaculture and Dredged Material Management in Containment Areas

There are at least two general containment area management techniques that could be compatible with aquaculture. Figure 7a depicts the placement of dredged material into a containment area surrounded by a single primary dike system. Distribution of the dredged material would be dependent on the size (surface area) of the containment and the relative volume and physical

Figure 4. Containment area dike in Texas

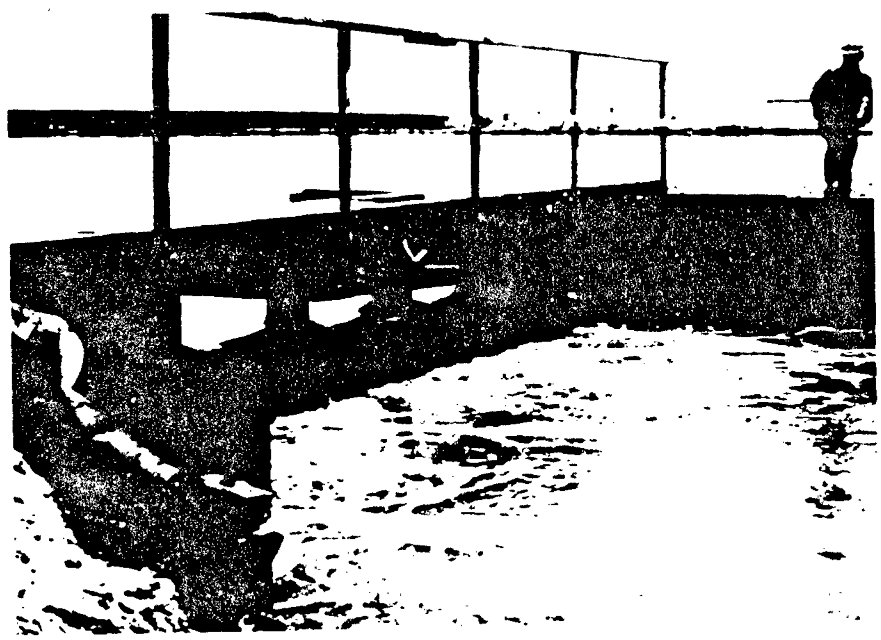
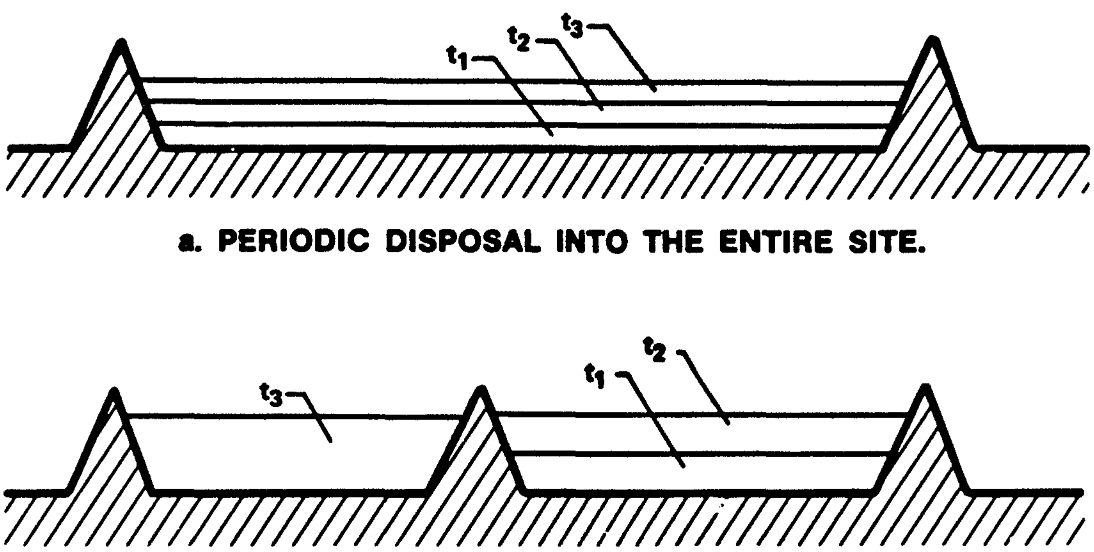


Figure 5. Weir-type spillway structure used in dredged material containment areas

Figure 6. Drop-inlet-type spillway structure used in dredged material containment areas



t = time in years and may vary between 1 and 15 from site to site

Figure 7. Concepts for combining dredged material containment and aquaculture operations

characteristics of the dredged material, together with controlled disposal operation conditions like pipeline placement and movement. It is unlikely, though not impossible, that culture operations could be sustained within a Figure 7a-configured site during active disposal. A small volume of dredged material disposed into a large containment area together with a species tolerant to suspended sediments is one workable scenario. Figure 7b depicts a containment area divided into multiple compartments or cells which would be filled sequentially over the life of the area. Construction of secondary, internal dikes produces a configuration with numerous operational advantages over an undivided one. The most obvious benefit would be related to the separation of one or more cells from dredged material disposal for an extended period of time. A more or less continuous aquaculture operation would be possible in such a site even during dredged material disposal operations. The 7b configuration has an additional benefit in a new site because it also separates the aquaculture operation from potentially chemically contaminated dredged material--a source of perceived even if not actual production or marketing problems.

The length of time following a disposal event before aquaculture activities could begin would be a site-specific variable depending on the site's size and configuration, the volume and character of the dredged material, and the possible use of dredged material dewatering and other volume-reducing techniques for efficient containment area management. A site without cells may not be available to aquaculture during the active dewatering period. Otherwise, aquaculture and dewatering objectives are totally compatible.

WORKSHOP ON CONTAINMENT AREA AQUACULTURE

A Corps-sponsored, 2-day workshop on aquaculture and dredged material containment areas was conducted in 1982 (8). It was attended by about 125 persons representing the Corps, other Federal agencies, state agencies, the aquaculture industry, the commercial fishing industry, and the academic research community. The specific objectives of the workshop were to:

a. Assess the utility of current aquaculture technology and its possible application to containment area aquaculture.

b. Identify research needs in containment area aquaculture.

c. Assess the potential for aquaculture in containment areas containing contaminated material.

d. Discuss user guidelines for establishing and operating aquaculture facilities in containment areas.

e. Propose designs for an economically attractive program of multiple use of containment areas for dredged material disposal and aquaculture.

Presentations by invited speakers from both commercial operations and research institutions occupied the first day of the workshop. A preliminary session related available aquaculture technology to containment area

aquaculture, and identified similarities and differences. This session also served as an overview of warmwater aquaculture practices and provided a common technical base for all participants.

The second day was devoted to problem solving. Five discussion groups, each consisting of a moderator-led core of specialists, were charged with providing specific topic-related recommendations and guidelines for establishing and operating profitable aquaculture facilities in dredged material containment areas.

A list of invited papers, speakers, discussion group topics, and group moderators is given in Table 1. A summary of the significant discussions is presented below.

TABLE 1. WORKSHOP AGENDA

Title	Speaker/Moderator
Plenary Session	
Welcome	COL Alan Laubscher Galveston District Engineer
Opening Remarks	Mr. Jesse Pfeiffer Directorate of R&D, OCE
Site Description of DMCAs: Overview of Physical, Chemical, and Biological Features	Mr. Rick Medina Galveston District
Applicability, Cost, and Benefits of Aquaculture in Containment Areas	Mr. John Lunz, WES
Operating an Aquaculture Facility in a DMCA:	
Legal Framework	Mr. Durwood Dugger and Mr. Michael Roegge Commercial Shrimp Culture International, Inc.
Production Economics	Dr. Addison Lawrence Texas A&M University (TAMU) Marine Experiment Station

(Continued)

TABLE 1. (Continued)

Title	Speaker/Moderator
Plenary Session (Continued)	
Review of Species Suitable for DMCA Culture:	
Fresh Water	Dr. Robert Stickney TAMU
Marine	Mr. Walter Tatum Claude Peteet Mariculture Center
Market Economic of Potential Products	Dr. John Waldrop and Dr. James Dillard Mississippi State University
Pond Management:	
Polyculture versus Monoculture	Dr. R. Kirk Strawn TAMU
Water Quality Criteria and Control	Mr. William Hollerman Auburn University
Health and Disease Control	Dr. Ken Johnson, TAMU
Predator and Competitor Control, Feeding/Fertilization, and Environmental Modifications	Mr. Walter Tatum
Aquaculture in Rice Field Impoundments: Model for DMCA Culture	Dr. John Dean University of South Carolina
Selection Criteria and Procedures for Establishing Aquaculture Facilities in Existing DMCAs	Mr. Dennis Milligan Dow Chemical USA
DMCA Design for Multiple Use: Aquaculture and Dredged Material Containment	Mr. Richard H. Highfill USDA Soil Conservation Service
Use of Contaminated Dredged Material Containment Sties: Possible Problems and Alternative Uses	Dr. Henry Tatem, WES

(Continued)

TABLE 1. (Concluded)

Title	Speaker/Moderator
Discussion Groups	
Laws Governing Acquisition, Maintenance, and Operation of DMCAs	Mr. Rick Harrison Galveston District
Target Species Selection and Management:	
Marine/Brackish Water	Dr. David Aldrich TAMU - Galveston
Fresh Water	Dr. Robert Romaire Louisiana State University
Aquaculture Operations in Contaminated Material Disposal Sites	Mr. James Andreasen Field Research Station of the Columbia Laboratory Mr. James Mansky New York District
Economics of DMCA Aquaculture	Mr. Michael Jones TAMU Mariculture Laboratory
Legal Aspects of DMCA Aquaculture	Mr. Bart Theberge Virginia Institute of Marine Science

Benefits of Containment Areas to Owners, Users, and the Corps of Engineers

Parties involved in commercial containment area aquaculture could realize significant benefits from multiple use of containment areas. Freshwater and coastal containment areas offer the benefits of desirable location and reduced construction and maintenance costs to aquaculturists/entrepreneurs. Local public interests could gain from the development of containment area aquaculture through employment opportunities and enhanced tax revenues.

A financially profitable multiple use of containment areas would also benefit owners of disposal acreage and the Corps. Property owners would receive compensation for the use of their land both as a containment area and for aquaculture. This would serve as a financial incentive to property owners

to make acreage more readily available for containment of dredged material. In addition to the improved real estate availability, the Corps would benefit from positive publicity generated by its efforts to cooperate with local interests and from promoting the use of what had been popularly perceived as biologically and economically unproductive acreage.

Aquaculture Products

Aquaculture in containment areas could be designed to produce crops for commercial harvest or could be directed toward producing fish or shellfish stocks for release to augment depressed natural populations. Current aquaculture-for-release programs in California, Texas, Japan, and the Middle East use natural and artificial coastal ponds, lagoons, and embayments for their propagation programs (9),(10). Similar programs could easily be undertaken in containment areas.

Coastal impoundments and containment areas used for the culture of fish and shellfish can serve as prototypes illustrating the feasibility of containment area aquaculture. Fish, shrimp, crabs, and crayfish raised with a minimum management effort have been harvested from old rice field impoundments in South Carolina (11). An infrequently used contain ment area in Sabine Lake in Port Arthur, Texas, produced marketable crops of redfish, shrimp, and crab, again with little management effort (12). Shrimp cultured in a containment area near Freeport, Texas, as part of the Corps' Dredged Material Research Program were found to grow well and produce a wholesome crop (13). To emphasize the continuing interest in impoundment/containment area aquaculture, commercial concerns represented at the workshop had leased such acreage for aquaculture development.

Areas of Concern/Potential Problems

Site characteristics

Containment areas exhibit a wide range of variability; location, size, construction, compatibility of aquaculture with disposal requirements, and a myriad of other site-specific physical and chemical features make each containment area unique. Not all containment areas will be suitable for aquaculture, but a significant number have the proper combination of features to support aquaculture. Crucial to developing aquaculture as a secondary use of containment areas is the fact that aquaculture will be possible only if it is compatible with the disposal requirements and schedules imposed by the intended primary use of the site, i.e. dredged material disposal. Only when both the aquaculturist's and the disposal agency's requirements are met can the site be developed for aquaculture.

Site acquisition and permitting

Site development and pond management practices are expected to be similar to those presently used in commercial aquaculture operations. Major exceptions lie in the areas of site acquisition by entrepreneurs and permit-granting procedures. Existing easement agreements must be amended, requiring prospective aquaculturists to reach separate agreements with both the property owner and the Corps. Representatives of commercial aquaculture enterprises claim that

the current permitting process is so involved and complex that the growth of aquaculture in the United States is effectively thwarted. Having the Corps involved in promoting and developing aquaculture in addition to retaining its traditional role in the permitting process would, in the view of many of the workshop participants, expedite the process in the future.

Use of contaminated sediments

The question of sediment contaminants and their possible effects on cultured organisms was another important area of concern. Material dredged from areas with heavy navigation traffic usually contain contaminants. The results of recent experiments designed to determine the effects of high contaminant concentrations on marine and freshwater organisms suggest that even high contaminant levels in sediments do not necessarily produce toxic effects in test organisms nor do they promote the accumulation of large concentrations of contaminants in the tissue of these organisms. Of course, these results vary with the type of contaminant, sediment conditions, and species of organism.

While information is lacking on many aspects of contaminant effects on species of interest to aquaculturists, this was not viewed as a problem. Caution and additional research were advised in dealing with potentially contaminated sediments.

Economics

From an economic veiwpoint, containment area aquaculture appears favorable. Participants with experience in both finfish and shrimp culture pointed out the great degree of similarity in the economic and marketing requirements between current aquaculture operations and those proposed for containment areas. Capital investment requirements could be significantly less. Simplified land acquisition, reduced land costs, shared costs of dike construction and maintenance expenses, and an expedited permitting process would all contribute to reducing capital costs. Operating costs, depending on both site and species cultured, were not so readily analyzed. But no extraordinary additional costs were anticipated.

Physical plant

Pond construction and modification for aquaculture would be site- and species-specific. If a containment area satisfied initial geotechnical and engineering requirements, constructing additional dikes, installing water control equipment, and other necessary modifications should follow the procedures employed in conventional operations. Cooperative efforts involving aquaculturists, the U. S. Department of Agriculture Soil Conservation Service, and the Corps were recommended for developing designs and specifying any modifications necessary for using containment areas for aquaculture.

Management concerns

Health considerations, water quality, and species management techniques for containment area culture should be identical to current practices, although the effects of large amounts of fine sediment in the containment area ponds

and the lack of experience in managing large-scale aquaculture operations pose questions that still need to be answered. Management procedures for large ponds have not been developed for many species simply because large ponds have not been generally available. With increased availability afforded by the widespread use of containment area acreage, appropriate techniques will rapidly evolve. Similarly, adequate water exchange, aeration, and harvest techniques should overcome many difficulties created by the presence of large amounts of fine sediments.

Compatible activities

Dredged material disposal and aquaculture can coexist in several ways. Crops may be cultured between disposal events, as in the Freeport demonstration, or the containment area may be subdivided into cells to be filled sequentially, permitting concurrent aquaculture and disposal operations in separate cells. With either system, aquaculture operations would cease as the containment area approached capacity.

Prospects of success

The conclusions of the plenary session and group discussions were that aquaculture in active containment areas was a feasible, cost-effective, and compatible multiple use of containment areas. With rare exceptions, existing technology could be directly applied to containment area aquaculture, making the concept practical with little additional research and development investment required. Those problem areas and research needs identified during the workshop were judged to be tractable and would not hinder the application of this concept. The needs of the local area, interests of the involved parties, and technical constraints will determine which type of culture operation (commercial or stock augmentation) and which species would be most suitable for a given area.

Prospects for culture of freshwater organisms in dredged material containment areas are bright. The large successful industries centered on crayfish, catfish, trout, and bait minnows can provide both the technical expertise and sources of stock needed for developing a profitable operation. The technology involved in freshwater fish culture is both well defined and compatible with culture plans envisioned for containment areas.

Redfish, exotic and native shrimp, hybrid striped bass, bait shrimp and minnows, and waterfowl are the most promising species for marine/brackish water culture. In contrast with the status of freshwater species aquaculture, the technology for the culture of many marine species has only recently advanced to the commercial level. The completion of shrimp life cycles under laboratory conditions, developing redfish propagation techniques, and other recent biological advances permit a cautiously optimistic assessment of the prospects for the culture of these and other marine species.

Workshop participants reached a consensus that aquaculture as a secondary use of containment areas would be both profitable and desirable. Pilot-scale demonstration projects under various field conditions and research directed at the potential problem areas were recommended. The technical information shared at the workshop and the support generated for this concept by the

represented agencies and interests combined to provide a solid foundation for the further development of the aquaculture concept.

The proceedings of the workshop are available and can be obtained by writing to the author.

THE FUTURE OF CONTAINMENT AREA AQUACULTURE

Aquaculture is a capital-intensive, risky enterprise. Money-lending institutions are reluctant to provide loans to aquaculturists operating under conditions that are new, different, unprecedented, and therefore too risky (6). In order for the private sector to adopt a concept that has been evolving so positively to date, it will be necessary to conduct, document, and advertise the results of a successful, real-scale field demonstration project. The existence of the results of the Freeport, Texas, field study conducted in 1976, the awareness of new technologies, the more attractive economic conditions, and the consensus of the workshop participants about the merits of the concept and the prospects of success are simply not adequate to induce the private sector to invest a million or more dollars in the concept. Huguenin and Webber (13) discussed the transition and scale-up of research results to commercial marine aquaculture systems. They stated,

> Some scientists viewed the development of marine aquaculture as strictly a biological and biochemical problem. The problems most commonly mentioned as limiting are disease control, nutrition, and larval rearing. The role of the technologist is usually viewed basically as providing support in the development of experimental equipment. Large scale systems management aspects are generally not even considered. The hope is to carry out sufficient experimentation in the laboratory so as to answer all the critical questions limiting large scale practical applications. Only then is it judged necessary to factor in seriously the engineering, marketing, and economic aspects. Many of the failures to date can be partially attributed to this neglect of the basic problems involved. Probably the biggest misunderstanding is the assumption that the scale-up of laboratory experiments to commercial size is a low-risk, straightforward linear bioengineering process. Thus, it is considered that there is little need for engineering or systems management input to experimental design or determining priorities required to guide research efforts into productive channels.

Table 2 is reprinted from their paper and presents the many basic differences in objectives, criteria, and other features when experimental systems and much larger applications are compared.

The merits of the concept are unquestionable. But the critical desk-top analyses have taken the idea about as far as it can go. Before the concept is

TABLE 2. DIFFERENCES AMONG TYPICAL AQUACULTURAL SYSTEM DEVELOPMENT STAGES (13)

	Initial Experiments	Pilot Plant	Large-Scale Application
Size	Desk top or equivalent	High variable; may be full-scale module	1-10,000 ha
Objectives	Research	Production research	Economical product
Primary outputs	Research data	Management and scale-up information	Tons of seafood/financial profit
Environment	Indoor laboratory	Indoors or outdoors	Usually exposed year-round
Period of operations	Short periods of testing	Intermittent	Continuous year-round, if possible
Staff skill and manning levels	Very high	High	Low
Efficiency of processes	Unimportant	Important	Critical
Economics of operations	Unimportant	Relatively unimportant	Critical
Magnitude of consequences of failures	Very low	Moderate	Very high

likely to be tried by an American aquaculturist working together with coordinated, Corps dredged material containment operations, a Federally subsidized and successful full-scale field demonstration program will need to be conducted.

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